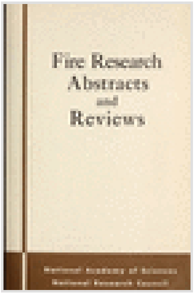

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Fire Research Abstracts and Reviews

National Academy of Sciences

FIRE RESEARCH ABSTRACTS AND REVIEWS

Robert M. Fristrom, Editor

Geraldine A. Fristrom, Associate Editor

The Committee on Fire Research

FIRE RESEARCH ABSTRACTS AND REVIEWS will abstract papers published in scientific journals, progress reports of sponsored research, patents, and research reports from technical laboratories. At intervals, reviews on subjects of particular importance will be published. The coverage will be limited to articles of significance in fire research, centered on the quantitative understanding of fire and its spread.

Editor: Robert M. Fristrom, Applied Physics Laboratory
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Volume 15 Number 1

Fire Research Abstracts and Reviews

Committee on Fire Research
Division of Engineering
National Research Council

NATIONAL ACADEMY OF SCIENCES
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FOREWORD

Dr. Robert M. Fristrom, the Editor of *FRAR*, has been on a nine-month leave of absence (January–October 1973) from the Applied Physics Laboratory, The Johns Hopkins University. During this period he was a Humboldt Fellow at the University of Göttingen, West Germany. The Committee on Fire Research is very appreciative of Dr. Fristrom's having maintained his editorship of *FRAR* from abroad during this period and welcomes him back to a continued role both with the Committee and this publication.

America Burning, the final report of the Presidential Commission on Fire Prevention and Control, was released to the public in May of this year. Many of the problems regarding a national fire program—for example, whether a centralized approach or a decentralized one is to be adopted—remain unsettled despite the Commission's recommendations. This document, as Dr. Walter G. Berl has pointed out in his review of the report, indicates more clearly what fire protection and a national fire program could mean for the United States. In this light, the document is a welcome and much needed catalyst for decisions yet to be made.

This issue also contains two review articles by Yoshio Tsuchiya (National Research Council of Canada), both related to fire research in Japan. The first discusses research activities; the second is a bibliography focused primarily on articles available in English.

NELSON T. GRISAMORE, *Executive Secretary*
Committee on Fire Research

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Review of AMERICA BURNING: The Report of the National Commission on Fire Prevention and Control

W. G. BERL

Applied Physics Laboratory, The Johns Hopkins University

The Report of the National Commission on Fire Prevention and Control is a remarkable and thoughtful document. It deserves to be studied by everyone involved in activities that impinge on the multifaceted problems of fire and their effects on people and property. Its value is in providing a vision of what a balanced fire program in the U.S. *could* be, why it is necessary to make new departures *now* and, in doing so, *how* to strengthen a public service that would gain a great deal from inputs on a national scale.

The origin of the Commission was Public Law 90–259, passed in 1968. It expanded the authority of the National Bureau of Standards to enlarge its Fire Research and Safety Program. Simultaneously, a National Commission was established to suggest additional steps to reduce the detrimental effects of fire. However, the realities of political decision-making that determine through the budgetary process what directives will be translated into actions, required the Commission to paint a much wider canvas than was suggested in the legislation. The reason was that the expansion of the Bureau of Standards program (which was to have been paid for by a $5,000,000 appropriation in F.Y. 1969) did not take place. Many of the key assignments were not funded. Therefore, the Commission in its 1973 Report had to review anew program items previously assigned to the NBS in the Fire Research and Safety Act of 1968 (such as investigation of fire causes, educational and training programs, fire information services, etc.) and to recommend again their adoption.

The Commission was appointed in 1971 and completed its assignment in May 1973. Its 20 members included a broad cross-section of persons concerned with public fire safety, fire suppression, fire prevention, the economics of fire losses, education in the fire field. Interested government departments, firefighters, and the public were also represented on the Commission (Appendix I).

Its investigative work was accomplished by hearing witnesses at five public hearings (on Fire Issues, Fire Services, Fire and the Built Environment, Fire Prevention), authorizing special studies, and analyzing position papers. The Final Report is subdivided into five major divisions (The Fire Services, Fire and the Built Environment, Fire and the Rural Wildlands Environment, Fire Prevention, Programs for the Future) and 20 chapters in which 90 recommendations were developed.

What are the principal conclusions? The central recommendation is that a permanent federal agency, a U.S. Fire Administration, be established which is to act as a focus and as a spur for the resolution of problems that will not bend to local or state-wide attacks. This Administration should concern itself primarily with:

- the formation of a National Fire Academy that would support ongoing local and regional efforts as well as institute nation-wide training programs not now existing;
- the setting up of an Information System that includes data collection and analysis, as well as information exchanges;
- encouragement of research and development in physical, behavioral and engineering areas not currently undertaken because of lack of funds;
- and the support of local or state model programs concerned with the preparation of integrated contingency plans for fire safety and control.

Despite these weaknesses and existing divergences in emphasis, the Report has, for the first time, given a picture of U.S. fire problems that goes far beyond special pleading for a particular improvement. Instead it has taken a broad view of the place of fire protection in society. It has included in its compass virtually all aspects in which fires upset normal life, such as medical and economic problems. It discusses their reduction through education, research, and improved technology. It has given broad guidelines for a vastly improved administrative arrangement on the federal level and has pointed out with clarity a number of currently inadequate functions that require federal internvention for their implementation (Fire Academy, Data Analysis). The authors of the Report are under no illusion that local or state organizations in being should be replaced by other administrative arrangements, or that the specific problems of individual situations could be solved by a centralized agency. However, they make the overwhelmingly important point that *some* problems need to be attacked on the national level, that the results of such endeavors would quickly reach the individual interested parties and that in a spirit of cooperation very substantial progress in fire damage reduction could be achieved.

This recommendation for establishing a Fire Administration with functions that cover currently unfilled national needs is the crucial and vitally important contribution of the Commission. The difficulties of implementing this specific recommendation are considerable. In what Federal Department should it be located? The Commission recommended the Department of Housing and Urban Development (HUD). But already at the first round of hearings on legislation to provide for a national fire program this proposal has come under attack, based on HUD's limited previous experience in the fire field and comparative lack of research-and-development-oriented facilities. What should the Fire Academy do? The Commission did not publish a detailed organization plan, leaving much room for varied interpretations of its functions, organization, scale and location. Grant disbursal to local communities for specific tasks has also been criticized as being contrary to the policy of revenue sharing. And yet, the arguments in favor of a Fire Administration are overwhelming. Twenty thousand municipal fire departments, budgeted from local taxes for specific functions, cannot all be expected to undertake projects that would best be done only once, but with adequate resources, so as to benefit everyone. Nor can municipalities independently evaluate the merits and hazards of building materials or of novel designs and determine their influence on existing building codes. Nor can training and teaching functions be left to each separate jurisdiction for independent development. Equipment modernization, tactics and communication assessments, insights into the physical and social causes of fire, the collection and analysis of fire incident statistics and their interpretation are best done in a few places where an experienced and knowledgeable staff can be asembled. Their findings, through demonstrations and example, can then be passed on to the interested units at a rate limited only by local needs and wishes.

In addition, the Report enumerated several score of recommendations addressed to a multitude of Federal agencies. High on this list are pleas for a substantial effort dedicated to public education on fire safety: fire education for educators, for students, for specialized occupations, and for the general public, utilizing the full spectrum of available media. Another set of recommendations deals with a major effort to equip buildings with early-warning fire detectors and, where warranted by multioccupancy, to install automatic suppression devices.

The Report suffers from several deficiencies that may handicap its speedy implementation. It does not carry out the initial change of Public Law 90–259 which requested detailed analyses and evaluations of specific areas of fire prevention and suppression, such as existing fire suppression methods, existing evaluation of training, fire communication techniques, administrative problems, etc. As a consequence, the Report is weak on supporting facts (there are very few citations to the best available literature in the field or descriptions of active investigations that are likely to have an effect on future practice) and cannot, therefore, be considered a satisfactory benchmark from which to measure the value of the many proposed recommendations. Cited statistics are scarce and do not extend backwards in time to establish trends (Appendix II). There are few references to the experiences of other countries that have already solved satisfactorily some of the problems raised in the Report. It has already been mentioned that none of the major recommendations (Fire Academy, Data Analysis, Model Programs and Grants) is worked out in sufficient detail regarding objectives, content, and staffing to give insights into how the suggested budget request of $153,000,000/year was obtained (Appendix III). Thus one must reserve judgment whether, and on what basis, the partial and the total budgets have been properly obtained. In view of this uncertain base, it is not too surprising that a number of legislative proposals have been introduced in Congress with widely differing content and budget requests.

Appendix I

THE COMMISSIONERS

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Eugene M. Sober, P.E., senior fire safety analyst
Joe Swartz, operations research analyst detailed by National Bureau of Standards

Appendix II

1971 FIRE LOSS DATA

Category	Life loss		Property loss		Fires	
	Number	Percent of total	Million dollars	Percent of total	Number	Percent of total
Residential (houses, apartments and hotels)	6,600	56	$874.1	31.9	699,000	25.6
Commercial (public assembly, educational, institutional, mercantile and office)	970 (with Industrial)	8 (with Industrial)	580.5	21.1	141,400	5.2
Industrial (basic industry, storage, manufacturing and miscellaneous			811.6	29.6	156,500	5.7
Building fires (total)	7,570[1]	64	$2,266.2[4]	82.6	996,900[4]	36.5
Brush, rubbish, grass	([2])	([2])	([3])	([3])	1,076,300	39.5
Forest fires	20	0.2	$119.0	4.4	111,500	4.1
Other outdoor fires	([2])	([2])	26.0	0.9	22,000	0.8
Aerospace vehicles and aircraft	125	1.1	192.0	7.0	200	...
Motor vehicles—farm/construction	3,950 (both motor vehicle rows)	33.3	16.12	0.6	19,200	0.7
Motor vehicles—pleasure/transportation		....	96.54	3.5	482,400	17.7
Ships, railroads, etc.	185	1.5	27.60	1.0	20,000	0.7
Non-building fires (total)	4,280[1]	36.1	$479.26[4]	17.4	1,731,600[4]	63.5
Grand total	11,850[4]	100	$2,743.46[4]	100	2,728,500[4]	100

[1] NFPA unofficial estimate for 1971.
[2] No separate estimates; totals included in other categories.
[3] No loss assumed for this type fire.
[4] NFPA official estimate for 1971.

Appendix III

TABLE 19–2

Annual Program Operating Budgets

U.S. Fire Administration	$124,840,000
Local fire master plan development	30,000,000[1]
State and local training assistance	30,000,000[1]
Research	26,000,000[2]
Equipment upgrading assistance	15,000,000[1]
Public education	9,600,000
Firefighter personal protective equipment	4,000,000[1]
National fire data system	3,740,000[1]
National Fire Academy	4,000,000
Administration	2,500,000
Other programs	28,250,000
Burn treatment center, unit and program development (HEW)	5,000,000
National Institutes of Health program (burn and smoke research) (HEW)	3,250,000
Rural fire protection (USDA, Title IV of Public Law 92-419)	7,000,000[3]
Detection and alarm systems and built-in protection loan insurance (HUD)	10,000,000
Research and engineering-based technology program (NBS)	3,000,000
Total	$153,090,000[4]

[1] These Federal programs require State and local governments to provide matching participation.

[2] The $26 million does not include the current fire research budgets of Federal agencies. Funds shown here would be used to contract with public and private agencies where appropriate.

[3] This was the recommended annual funding level for a three-year conservative rural fire protection program. Funds have not, as yet, been appropriated, and the Commission feels that funding is more than justified by the losses in the areas covered.

[4] This budget is an estimate of the average annual expenditure for the first 5 years. The mix of expenditures will vary as staffs are recruited and trained.

Fire Research in Japan

Y. TSUCHIYA

Division of Building Research, National Research Council of Canada

During July 1972, the author had an opportunity to visit 16 Japanese fire research organizations. In addition, discussions were held with representatives of six other organizations. Fire research in Japan is quite active, with many papers being published and many more being presented at meetings of fire prevention and related societies. These activities, however, are not well known outside the country because of the language barrier. There have been two English reports on Japanese fire research, one by Dr. T. Kinbara[1] who reported the historical development of fire prevention and fire research before and after World War II plus various other related activities up to the year 1961, and the other by Dr. H. W. Emmons who in 1966 visited two Japanese fire research organizations in his extensive survey of world fire research.[2] Recent economic progress in Japan has given rise to an increase in fire research, especially by the government. Many new laboratory buildings have been or are being built and facilities are being improved, although the number of government researches is fixed by a strict quota system.

Japanese fire research is being done by government, universities, and industries. Several government ministries are concerned, among which the Fire Defense Agency (under the Ministry of Home Affairs) is the one with the greatest responsibility in this field. The function of the Agency includes drafting of fire codes, fire statistics, training of fire personnel, and fire research. Research in the Agency is carried out by the Fire Research Institute. Prevention of building fires based on building design and drafting building codes are the responsibilities of the Ministry of Construction. The Building Research Institute comes under this ministry. These two institutes are the major fire research institutes in the national government. Other ministries concerned with fire are the Ministry of Trade and Industry for the interest of consumers, the Ministry of Labor for safety of industrial workers, and the Ministry of Agriculture and Forestry for forest fire and fire behavior of forest products. Metropolitan Tokyo because of its size, population, and importance, has its own fire defense agency, the Tokyo Metropolitan Fire Defense Board, which has the Fire Science Laboratory, the second largest fire research establishment in Japan.

There are two major streams in university fire research: one is the science of combustion, the other, architectural engineering, both of which involve several departments. The universities provide scientists and engineers for government and industrial research. On the other hand, established or retired researchers in the government often move to faculty positions. There are so many professors interested in fire research that the list included in the latter part of this report is not complete.

The present survey does not do justice to fire research in industry. There are many research groups in construction firms, building materials manufacturers, and manufacturers of fire fighting equipment and detectors, but they are not free to disclose their research. The author contacted only two firms during his stay in Japan, but even from this limited knowledge it can be said that industrial research is very active; they have good facilities, capable research staff, and clear practical objectives.

In addition, there is considerable activity in group studies or committee work among researchers of university, government, and industry. If a specific subject is considered important or urgent, a ministry of government or an industrial association requests research or investigation by a committee formed for that specific purpose. Some examples of such works are development of a standard test for toxicity of combustion products; research and investigation on fire endurance of steel bridges; research on the prevention of fire in a highway tunnel, and investigation of the "Sennichi" fire (in which about 100 people were killed by combustion products).

Budgets for research in government have been increased appreciably in the past several years. There are three financial sources for research operations. First is the routine research budget that allows a fixed amount of about $2,500 per year per researcher. The second is the special project budget. Both of these come from the ministry to which an institute belongs. The third source is for interministry projects, and these monies come from the Agency of Science and Technology. The second and third funds vary from year to year, depending on the importance of the project and the specific need for funds. The total research budget has been increasing about 13 per cent per year in recent years. The budget for research operations approximately equals the total of the salaries paid in an institute. Funds for university research are generally insufficient, and research facilities are not very good except at just a few universities. The smallest unit in Japanese universities is called a *koza*, which consists of a professor, an associate professor, two assistants and some graduate students. The regular budget for a *koza* is from $3,000 to $7,000 per year. If extra money is needed for a specific project, they may apply to the Scientific Research Fund in the Ministry of Education. In addition to this, some professors belong to a committee for a specific study sponsored by a government or an industrial association. They may also work on a project sponsored by industry.

Results of research work are discussed at meetings of scientific and engineering societies and published in various journals. The most authoritative society on fire is the Japanese Association of Fire Science and Engineering (formerly the Fire Prevention Society of Japan), 2–4–16, Yayoicho, Bunkyo-ku, Tokyo. The Association's president is Dr. T. Kinbara. This association has been promoting fire prevention since 1950 by encouraging research and spreading knowledge on fire science and engineering. The society has some 2,700 members comprised of researchers, engineers, insurance companies and fire prevention personnel. They publish two journals; one is the *Bulletin of the Fire Prevention Society of Japan*, in Japanese with English abstracts for original papers, published biannually. The editor is Mr. T. Moriya, Fire Research Institute. The other, published quarterly, is *Kasai* (*Fire Hazard*) also in Japanese, which contains general knowledge of fire prevention. The editor is Professor K. Tsukamoto, Nippon University. Besides publishing the two journals, the society meets biannually for discussion of original research works and organizes a fire science seminar on up-to-date topics. The latest topics were Smoke Evolution and Movement in a Building Fire (1971);

Hazardous Materials (1972); and Toxic Gases in Fires (1972). The society has several standing committees that are working on research and investigation of special problems at the request of government and other organizations.

Some other societies concerned with fire research are the Architectural Institute of Japan, the Safety Engineering Society, the Combustion Institute, and the Chemical Society of Japan. A bibliography of papers on fire research compiled by the author was published in 1972.[3]

Current research projects are listed in the latter part of this report by research agency. Some that are of direct interest to the author are described below in some detail.

Toxicity of Combustion Products

There are two types of approach to this problem. One deals with the analysis of combustion products in order to determine species and quantities of toxic products. This approach is taken by at least three groups who are making some effort towards establishing standard methods of analysis for various toxic components. The other approach is to determine toxicity of combustion products by animal experiments; here, too, at least three groups are involved.

A committee is engaged in developing a standard test for toxicity of combustion products from building materials at the request of the Ministry of Construction. One of the methods under development consists of exposing several mice to combustion products. The time to incapacitating mice under varied conditions of combustion is then determined. Some medical doctors are studying the effect of oxygen depletion, carbon monoxide, and other common toxic combustion products on human beings.

Smoke in Fires

There are several projects under investigation on smoke produced by fire. Visibility through smoke is being determined at the Fire Research Institute. Performance of smoke detectors and methods for testing them are being studied by both government and industry. An electric device for quick precipitation of smoke has been developed at the Fire Science Laboratory. The amount of smoke produced from building materials is being determined at the Building Research Institute.

Computation of smoke movement and its control is also being studied at the Building Research Institute, one of the most advanced in the world. The concentration of smoke in various parts of a given building at different times is calculated, as is the time necessary for the evacuation of people from the building. If the building is not safe for the occupants, various smoke control measures are introduced and the effect is simulated. The information obtained is then used for designing a fire-safe building. Basic data for this computation have been obtained by experiments in smoke towers and in existing buildings. Two smoke towers and two road tunnels are available in different organizations in the vicinity of Tokyo for use in large-scale experiments on combustion and smoke.

Systemization of Disaster Prevention Measures in a Building

In order to prevent disaster in a building, fire detection, extinguishment of fire, and control of smoke movement and of occupants must be done efficiently. Systemization of disaster prevention measures is one method of achieving this aim by integrating various measures into a single system controlled by one person or a computer. The control center of this system is then placed in a room in the building. Such a room is already required for high-rise buildings and underground buildings according to the recent edition of the Japanese building code, although its purpose thus far is limited to the control of smoke movement. Systemization is being studied mainly by manufacturers of fire detectors. Measures that have been considered in such systems include fire detection; extinguishment; emergency communication to fire department and to occupants; control of elevators, fire doors, and shutters; control of smoke movement; emergency lightir.g; and indication of evacuation routes.

Disaster Prevention in Urban Areas in a Major Earthquake

An analysis of many earthquakes in the Tokyo area suggests a high possibility of a major earthquake between 1978 and 2004 that most likely would be followed by a mass fire. Disaster prevention in urban areas, therefore, is a major interministry project. Experimental study on fire spread in a city, analysis of past conflagrations, effect of weather, operation research on fire fighting, simulation of the extent of damage and evacuation, and a fireproof base for fire fighting and refuge are all under investigation by various organizations. (A fireproof base is defined as a large space protected by tall fireproof buildings that will provide a refuge for people surrounded by a conflagration. The design and effect of such buildings are under study by large-scale crib fire experiments.)

Although the author's interest is confined mainly to fire research, he was pleased when an opportunity arose to see the Japanese training facilities for firemen. There are two grades of fire colleges in Japan: a national fire college under the jurisdiction of the Fire Defense Agency and provincial fire colleges. The former is for higher education of senior members of fire prevention personnel in national, provincial, and municipal governments. It also suggests curricula for the provincial colleges. The national fire college is located adjacent to the Fire Research Institute. A provincial fire college is established in each province for the training of firemen. Tokyo Fire College, which is one of them, is situated adjacent to the Fire Science Laboratory of the Tokyo Fire Defense Board. In 1971, the college trained 1,950 recruits of which one-third were university or college graduates; the others were institute or high school graduates. The college also gave advanced education to 4,000 established firemen.

Government and Industrial Fire Research

1. Fire Research Institute, Fire Defense Agency, Ministry of Home Affairs

Address: 14–1, Nakahara, 3-chome, Mitaka, Tokyo (3 miles from Kichijoji Station, Chūō-Line)
Director: Mr. Y. Kumano
Number of Staff: total, 59; research, 37
Budget: total, $620,000; research, $300,000
Publications: *Research Report of the Fire Research Institute* (in Japanese), biannually

This is the largest governmental research organization in Japan devoted to the science and technology of fire fighting. A detailed report of this Institute was prepared by Professor Emmons following his visit in 1966.[2] Since that time facilities have been greatly improved by the addition of a new main building, three laboratory buildings, and a large amount of equipment. At present there are 18 buildings with a total area of 7,440 m^2 plus many outside experimental facilities, all located on a 46,300 m^2 property. The Institute is divided into three research divisions who investigate the physical, chemical, and mechanical aspects of fire problems, respectively.

Basic research on combustion and suppression are being performed, in addition to research on practical problems. In the field of building fires, detection and suppression of a fire are the responsibilities of the institute, whereas fire prevention based on the design of a building is the responsibility of the Building Research Institute. Testing of fire fighting equipment and facilities, which used to be included as one of their functions, has been transferred to another organization.

The budget is classified into four categories: routine research work; special projects; projects related to atomic energy; and inter-ministry projects. Funds for the first two come from the Ministry of Home Affairs and for the last two from the Agency of Science and Technology. The percentage of the budget allocated to these four categories in 1971 was 35, 33, 12 and 21 per cent, respectively.

Some current research projects are as follows:

1. Routine Research Projects

1.1 Effect of weather on combustion—experimental
1.2 Fire simulation by an electric circuit
1.3 Effect of weather and topography on conflagrations—statistical
1.4 Fire caused by failure of a neon sign
1.5 Static charge caused by the eruption of flammable high pressure vapor
1.6 Visibility through smoke
1.7 Combustion products of organic materials
1.8 Aerial fire detection by thermo-vision
1.9 Combustion of liquid on a water surface
1.10 Flameproofing of high polymer
1.11 High-expansion foam
1.12 Synthetic foaming agent for alcohol fire
1.13 Effective use of water for crib fire
1.14 Thermal explosion of organic peroxides
1.15 Diffusion characteristics of flammable vapor
1.16 Efficiency of sprinkler heads
1.17 Development of water bombing equipment
1.18 Motorcycles for fighting forest fires
1.19 Escape chutes

2. Special Projects

2.1 Prevention of disaster at a major earthquake
  2.1.1 Natural resource water for fire fighting
  2.1.2 Flame spread in a conflagration

2.2 High-rise building and underground mall
- 2.2.1 Development of smoke indicator in an escape route; characterization of smoke detector; air curtain for smoke isolation
- 2.2.2 Technical standards for flame-proofing materials
- 2.2.3 Oxygen generating mask for firemen

3. Projects Related to Atomic Energy

3.1 Contamination by radio-active materials in fires
3.2 Fire resistance of atomic fuel and radio isotope container
3.3 Suppression of a fire in a hot-cave and a glove-box

4. Inter-Ministry Projects

4.1 Land slide
4.2 Prevention of disaster at a big earthquake
- 4.2.1 Spread of fire in a conflagration—investigation of cases and experimental work
- 4.2.2 Suppression of fire by aircraft

2. Building Research Institute, Ministry of Construction
Address: 28–8, 3-chome, Hyakunincho, Shinjuku-ku, Tokyo (5 minutes walk from Shin-ōkubo Station, Chuō-Line)
Director: Dr. K. Kawagoe
Number of Staff: total, 181; research, 67 (research on fire, 6)
Budget: total, $1,700,000; research on fire, $45,000
Publications: *BRI Research Paper* (in English), about five issues per year; *Report of Building Research Institute* (in Japanese with English abstracts)

This Institute, which is located in a built-up section of Tokyo, was also visited by Professor Emmons. According to a government relocation plan for research and educational organizations, it will be moved to a new location 50 miles north of Tokyo in 1975. For this reason, laboratory buildings are in rather poor condition. Although the fire research group of this Institute is relatively small, it is well-known outside the country because of its excellent contributions to fire research. The organization is divided into five divisions and twenty sections. Among these, the Organic Materials Section of the 2nd Division and the Fire Prevention Research Section of the 5th Division are active in fire research.

Some of the current research projects are development of a standard test for the toxicity of combustion products from building materials based on animal tests; computer simulation of smoke control in buildings; planning and experiment involving a fireproof base for refuge and a fire fighting center in the event of a conflagration caused by a major earthquake. A list of research projects is as follows:

1. Routine Research Projects

1.1 Disaster prevention techniques for buildings
- 1.1.1 Effect of interior finishing materials on the development of fire (Experimental fires are used to study the effect of retardant materials and the effect of application method on the flammability of interior finishing materials.)
- 1.1.2 Analysis of fire statistics

2. Special Projects

2.1 Disaster prevention in urban community

2.1.1 Fireproof base for refuge and fire fighting center
2.1.2 Smoke spread in underground and high-rise buildings
2.1.3 Hazard of combustion products in building fires

3. Inter-Ministry Projects

3.1 Conflagration-model experiment

3. Fire Science Laboratory, Tokyo Metropolitan Fire Board

Address: 2–52, Nishihara, Shibuya-ku, Tokyo (1/2 mile from Hatagaya Station, Keiō-Line)
Director: Mr. H. Imazu
Number of Staff: total, 41; research, 28
Budget: total, $100,000
Publications: *Report of Fire Science Laboratory* (in Japanese) annually

This laboratory is under the jurisdiction of the municipal government of Tokyo. Although it is the second largest fire research group in Japan, it is not well known outside the country. Research is directed towards practical problems and development of fire fighting techniques and equipment. A new laboratory building, with a floor area of 5,000 m^2 and costing 1.5 million dollars, has just been completed. Some of the main projects under study are as follows:

(1) Electrostatic smoke precipitator (To remove smoke from corridor or stairs, static electricity of 10k volts is applied to stretched wires.[4])
(2) Development of simple, low-cost, and light-weight equipment for producing high expansion foam
(3) Fire fighting equipment for individual homes
(4) Development of new fire extinguishing liquids

4. Industrial Products Research Institute, Agency of Industrial Science and Technology

Address: 21–2, 4-chome, Shimomaruko, Ōta-ku, Tokyo (1/2 mile from Shimomaruko Station, Mekama-Line)
Director: Dr. N. Akagawa
Number of Staff: total, 143; research, 105 (research on fire, 3)
Budget: research on fire, $50,000

One of the principal responsibilities of this Institute is to protect the consumers' interests. In connection with fire, they have started an investigation involving the analysis of combustion products from various plastic goods. They also have a continuing project on the development of flame-retardant surface-coating materials.

5. The Research Institute of Industrial Safety

Address: 5–35–1, Shiba, Minato-ku, Tokyo (5 minutes walk from Tamachi Station, Keihin-Line)

Director: Dr. S. Kōzuki
Number of Staff: total, 58; research, 40 (research on fire and explosion, 10)
Budget: total, $750,000; for research, $90,000
Publications: *Research Report of the Research Institute of Industrial Safety* (in Japanese with English abstract), about five issues per year, and some technical recommendations

This Institute was established to prevent industrial accidents. Research on the prevention of fire and explosion in industry is part of its work. A modern main laboratory building of 7,000 m² floor area was completed in 1971. Some of their research projects are as follows:

(1) Quenching distance of solids, a new testing method for combustibility of solids
(2) Ignition and flame propagation of plastics in oxygen-rich atmospheres
(3) Prevention of gas explosion caused by electric apparatus, determination of ignitability of gas mixtures, development of explosion-proof electric equipment, testing method for explosion-proof electric equipment

6. Resources Division No. 4, National Research Institute for Pollution and Resources, Agency of Industrial Science and Technology

Address: 4–26–10, Ukima, Kita-ku, Tokyo
Number of Staff: 42

This Division is responsible for research work on safety in mines. Some staff members are working on prevention of fire and explosion in mines. Projects underway in this field are spontaneous ignition, explosibility of gas mixtures and coal dust, flame-retardant treatment of wood and its smoke-producing property, and projectile fire extinguishment.

7. Engineering and Research Department, Fire and Marine Insurance Rating Association of Japan

Address: 9, 2-chome, Kanda-awajicho, Chiyoda-ku, Tokyo (5 minutes walk from Ochanomizu Station, Chuō-Line)
Director: Dr. Tatsunobu Izawa
Number of Staff: about 20 professionals
Publications: many educational books and pamphlets, and a journal for accident and disaster prevention, in Japanese.

Fire and Marine Insurance Rating Association of Japan is formed by 22 members of Japanese insurance companies. In order to establish insurance premium rates, the Engineering and Research Department collects information relative to insurance losses caused by fire, explosion, windstorm, earthquake, etc., and promotes research and investigation. For this purpose the department sponsors the Committee for Scientific Research on Accidents and Disasters. The department undertakes approval examination for sprinkler systems, fire alarm systems and other fire protection installations and equipment, and conducts tests on hazardous goods.

8. Fire Equipment Inspection Corporation

Address: 14–1, Nakahara, 3-chome, Mitaka, Tokyo (same location as Fire Research Institute)
President: Mr. K. Matsumura
Number of Staff: 93
Budget: total, \$2.6 million per annum

This Corporation was established as a non-profit organization in 1963 when fire service legislation was revised and inspection of fire service equipment became compulsory. The main testing laboratory (floor area 3,000 m^2) and a number of other buildings are located adjacent to the Fire Research Institute. The functions of this organization include inspection and testing of fire extinguishers and extinguishing agents, fire pumps and hoses, sprinkler heads, thermal detectors, smoke detectors, and flame retardants for fabrics.

Universities and Personnel Involved in Fire Research Activities

1. Professor M. Hamada (Department of Architecture, Tokyo Science College, Kagurazaka, Shinjuku-ku, Tokyo) is the former president of the Fire Prevention Society of Japan and a retired professor of the University of Tokyo. Many of the present researchers on building fires are graduates of his course. He has had many papers on fire and building components, city planning, and disaster published.
2. Associate Professor K. Kishitani (Department of Architecture, University of Tokyo, Bunkyo-ku, Tokyo) specializes in building materials research. He is an active member of committees on building materials and toxicity of combustion products.
3. Professor S. Horiuchi (Department of Architecture, University of Kyoto, Sakyo-ku, Kyoto) used to work at the Fire Research Institute. He devised a calculation method for the determination of the capacity of fire fighting force in a city.
4. Associate Professor T. Terai (Department of Architecture, University of Kyoto) is researching computation and experimental study on smoke flow in buildings based on a laminar-flow model.
5. Professor H. Saito (Department of Architecture, Chiba University, Yayoicho, Chiba, Chiba-ken) used to work at the Building Research Institute. He has authored many papers on the behavior of concrete and steel beam in a fire.
6. Professor K. Fujita (Tohoku Institute of Technology) is the former Director of the Building Research Institute. His main interest is control of smoke in buildings.
7. Professor T. Harada (Kanagawa University) is retired from the Tokyo Institute of Technology. Many of his papers on the behavior of reinforced concrete structure in fires have been published.
8. Associate Professor F. Furumura (Tokyo Institute of Technology) is investigating the behavior of steel and concrete beams in fires.
9. Professor S. Yokoi (Nippon University) is retired from the Building Research Institute. He has worked on the radiation from flames and the spread of fire in a building.

10. Professor T. Kinbara is President of Fire Prevention Society of Japan and was one of the founders of the society. Now retired from the University of Tokyo and Sophia University, he has authored many papers on the theory of combustion.
11. Associate Professor K. Akita (Department of Reaction Chemistry, University of Tokyo, Bunkyo-ku, Tokyo) is one of the active researchers on the science of combustion. His interest is mainly in ignition and combustion of cellulosic materials and combustion of liquid fuels.
12. Professor T. Handa (Department of Applied Chemistry, Tokyo Science College, Shinjuku-ku, Tokyo) is interested in ignition and combustion of wood, movement of smoke, and theoretical analysis of various flame-spread tests.
13. Professor H. Endo (College of Electro-Communication, Chōfu-shi, Tokyo) is doing work on the propagation of combustion on solid.
14. Associate Professor S. Sega (Toho University, Narashino-shi, Chiba-ken) is also researching the propagation of combustion on solid.
15. Professor H. Hatakeyama (Nisho-gakusha College), Vice-President of the Fire Prevention Society, is specializing in weather and fire.
16. Professor T. Kitagawa (Department of Safety Engineering, Yokohama National University) is interested in the prevention of fire and explosion in industry. He is the inventor of a colorimetric tube gas analyzer.
17. Professor K. Namba (Department of Reaction Chemistry, University of Tokyo, Bunkyo-ku, Tokyo) is conducting research on the combustion and explosion of hazardous materials.
18. Professor S. Tomisawa (Kitazato Medical College) is studying the toxic effect of combustion products on human beings.
19. Associate Professor H. Yamaguchi (Showa Medical College) is investigating the effect of oxygen depletion on human beings.
20. Professor S. Yoshimura (Tokyo Jikeikai Medical College) is researching carbon monoxide poisoning.
21. Dr. K. Yamamoto (Faculty of Medicine, Kyoto University) is studying toxicity of combustion products.

References

1. Kinbara, T. "A Survey of Fire Research in Japan," *Fire Research Abstracts and Reviews 3*(1), 1 (1961)
2. Emmons, H. W. "Fire Research—A Trip Report (1966–1967)," *Report No. 1, under National Science Foundation Grant No. GK-771, Division of Engineering and Applied Physics, Engineering Science Laboratory, Harvard University, Cambridge, Massachusetts*
3. Tsuchiya, Y. "Bibliography of Fire Research Publications in Japan (1961–1971)," *Bibliography No. 40, Division of Building Research, National Research Council of Canada* (June 1972)
4. *International Fire Chief 37*(9) (October–November 1971)

Bibliography of Fire Research Publications in Japan (1961–1971)

Y. TSUCHIYA

Division of Building Research, National Research Council of Canada

The Japanese are very active in fire research and have published many papers in this field. Much of the information contained in these papers, however, does not seem to have been used in the western world, even though many of the papers are written in English or have English abstracts.

This bibliography contains titles of original papers published in Japanese fire journals, or journals related to fire, between 1961 and 1971. Publications on the subject that appeared before 1961 are listed in "A Survey of Fire Research in Japan," by T. Kinbara, *Fire Research Abstracts and Reviews*, **3**(1), 1 (January 1961).

The entries in this present bibliography have been arranged by subject; articles are listed in chronological order, the most recent first. The format of entries is as follows:

a) title
b) author
c) organization
d) name, volume, page and year of journal
e) language in which paper is written
f) reference to *Fire Research Abstracts and Reviews* where applicable.

The English titles of the papers are, for the most part, the same as appeared on the published article. In a few cases, however, the present author has removed words of little meaning to shorten the title or to describe the content of the paper more accurately.

The source of the papers and the publishers of the journals are as follows:

Bulletin of the Fire Prevention Society of Japan; Fire Prevention Society of Japan, Gakukai-centre Building, Yayoi-cho, Bunkyo-ku, Tokyo

Report of Fire Research Institute of Japan; Fire Research Institute, Ministry of Home Affairs, 14–1, Nakahara 3-chome, Mitaka, Tokyo

Report of the Building Research Institute and *B.R.I. Research Paper* (formerly B.R.I. Occasional Report); Building Research Institute, Ministry of Construction, 4-chome, Hyakunin-cho, Shinjuku-ku, Tokyo

Transactions of the Architectural Institute of Japan; Architectural Institute of Japan, 3–2–19, Ginza, Chuo-ku, Tokyo

Journal of the Faculty of Engineering, University of Tokyo; Motofuji-cho, Bunkyo-ku, Tokyo

Abbreviations used in the entries are as follows:

J	in Japanese
JE	in Japanese with English Abstract
JG	in Japanese with German Abstract
E	in English

The information is stored on IBM punchcards and the listing is prepared by computer so that it can be revised quite easily. The present author would appreciate being informed of any omissions.

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"Ignition of Laminated Systems, Plywood and Fire-Retardant Plywood(1)," T. Handa et al. (Tokyo Sci. College), *Bull. Fire Prev. Soc.* **19**(2), 9, (1970) J, E

"Combustion and Smoke Evolution of Organic Materials in Fire," T. Handa, H. Suzuki (Tokyo Sci. College), K. Homma (Indust. Hygiene Lab.), *Bull. Fire Prev. Soc.* **18**(1), 21, (1968) J, E

"Spontaneous Ignition of Wooden Materials Heated for a Long Time at a Low Temperature," T. Kinbara (Sophia U.), A. Kawasaki (Police Headquarters Kanagawa Pref.), *Bull. Fire Prev. Soc.* **16**(2), 9, (1967) J, E

"Ignition of a Salt-Soaked Wooden Board by an Electric Current(1), T. Kinbara (U. of Tokyo), K. Takizawa (M.P.D. Crime Lab.), *Bull. Fire Prev. Soc.* **11**(2), 26, (1961) J, E

"On the Height of Flames from Burning Cribs," S. Yokoi (Build. Res. Inst.), *B.R.I. Occasional Report No. 12* (July 1963) E

"On the Height of Flames from Burning Cribs," S. Yokoi (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **13**(1), 22, (1963) J, E

"Structure of the Diffusion Flame of Liquid and Solid Fuels," K. Akita (Fire Res. Inst.), *Report Fire Res. Inst. No. 23*, 5 (March 1963) E

"On the Structure of Fire Diffusion Flame," K. Akita (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **10**(1), 6, (1961) J, E

"Heat Transfer Coefficient and Emissivity of Flame in a Burning Wooden House," T. Moriya, T. Jin, H. Shimada (Fire Res. Inst.), *Report Fire Res. Inst. No. 33*, 17 (March 1971) J, E

"Thermal Radiation from Oil Tank Fires," T. Yumoto (Fire Res. Inst.), *Report Fire Res. Inst. No. 33*, 23 (March 1971) J, E

Propagation

"Propagation of Combustion in Solid Materials(4): Downward Propagation of Smoldering through Vertical Tube of Paper," T. Kinbara (Sophia U.), H. Endo (U. of Electro-Communication), S. Sega (Toho U.), *Bull. Fire Prev. Soc.* **18**(1), 5, (1968) J, E

"Propagation of Combustion in Solid Materials(3): Temperature Distribution in a Smoldering Rod," T. Kinbara (Sophia U.), H. Endo (U. of Electro-Communication), S. Sega (Toho U.), *Bull. Fire Prev. Soc.* **18**(1), 1, (1968) J, E

"Downward Propagating of Smoldering through Vertical Uniform Rods," T. Kinbara (Sophia U.), H. Endo (U. of Electro-Communication), S. Sega (Toho U.), *Bull. Fire Prev. Soc.* **15**(2), 31, (1966) J, E

"Downward Propagation of Smoldering along a Vertical Sheet of Paper," T. Kinbara (Sophia U.), H. Endo (U. of Electro-Communication), S. Sega (Toho U.), *Bull. Fire Prev. Soc.* **14**(1, 2), 37, (1965) J, E

"Effects of Internal Linings on Spread of Fire at Its Early Stage," S. Yokoi (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **12**(1), 1, (1962) J, E

"Study on the Prevention of Fire-Spread Caused by Hot Upward Current," S. Yokoi (Build. Res. Inst.), *Report of B.R.I. No. 34* (Nov. 1960) E

Suppression

"Some Statistical Features on Extinction of Small Diffusion Flame of Burning Liquid with Sprays of Several Salt Solutions," H. Kida (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **18**(2), 1, (1969) J, E [*Fire Res. Abs. Rev.* **11**(3), 212]

"Required Quantity of Various Fire Extinguishing Agents(5): Planning of the Fire Extinguishing System," S. Yamashika (Fire Res. Inst.), *Report Fire Res. Inst. No. 33,* 13 (March 1971) J, E [*Fire Res. Abs. Rev.* **14**(2), 134]

"Required Quantity of Various Fire Extinguishing Agents(4): Fire-Fighting Foam," S. Yamashika (Fire Res. Inst.), *Report Fire Res. Inst. No. 33,* 7 (March 1971) J, E [*Fire Res. Abs. Rev.* **14**(2), 133]

"Required Quantity of Various Fire Extinguishing Agents(3): Open Tray Fire," S. Yamashika (Fire Res. Inst.), *Report Fire Res. Inst. No. 33,* 1 (March 1971) J, E [*Fire Res. Abs. Rev.* **14**(2), 133]

"Required Quantity of Various Fire Extinguishing Agents(2)," S. Yamashika, T. Morikawa (Fire Res. Inst.), *Report Fire Res. Inst. No. 32,* 37 (Dec. 1970) J, E

"Required Quantity of Various Fire Extinguishing Agents(1)," S. Yamashika (Fire Res. Inst.), *Report Fire Res. Inst. No. 32,* 31 (Dec. 1970) J, E

"Dry Powder Fire Extinguishing Agents(4)," S. Yamashika (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **20**(2), 29, (1971) J, E

"Dry Powder Fire Extinguishing Agents(3)," S. Yamashika (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **18**(2), 23, (1969) J, E

"Powder Fire Extinguishing Agents(3): Action of Chemical Powder on Materials such as Wood at the Time of Thermal Decomposition," S. Yamashika (Fire Res. Inst.), *Report Fire Res. Inst. No. 29,* 1 (March 1969) J, E

"Dry Powder Fire Extinguishing Agents(2): Effect of Dry Powder on Wood Fire," S. Yamashika, H. Kida (Fire Res. Inst.), *Report Fire Res. Inst. No. 26,* 47 (March 1965) J, E

"Dry Powder Fire Extinguishing Agents(1): Effect of Dry Powder on Hydrocarbon Diffusion Flame," S. Yamashika, H. Kida (Fire Res. Inst.), *Report Fire Res. Inst. No. 26*, 37 (March 1965) J, E

"Stability, Compatibility with Dry-Chemical, and Vapor-Security of Foam," S. Yamashika (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **16**(1), 1, (1966) J, E

"Evaluation of Extinguishing Power of Fire-Fighting Foaming Compounds in Small Scale Fire Test," R. Nii (Fire Res. Inst.), *Report Fire Res. Inst. No. 26*, 25 (March 1965) E

"Drainage of Air Foam in Case of Coexistence with a Principal Ingredient of Dry Chemical Extinguishing Agents and with a Petroleum," R. Nii (Fire Res. Inst.), *Report Fire Res. Inst. No. 23*, 1 (March 1963) J, E [*Fire Res. Abs. Rev.* **12**(1), 47]

"High Expansion Foam for Fire Fighting," Y. Matsukuma, M. Umezu, S. Yamao (Resource Res. Inst.), *Bull. Fire Prev. Soc.* **15**(1), 1, (1966) J, E

"Experimental Studies on the Quality of Sprinklers," S. Yamane, Y. Tanaka (Takenaka Komu-Ten Co.), *Bull. Fire Prev. Soc.* **16**(1), 9, (1966) J, E

"An Elementary Study on the Capacity of Water Supply Points," K. Yasuno (Japan Assoc. 1970 World Expo.), *Bull. Fire Prev. Soc.* **17**(1), 1, (1967) J, E

"Alcohol-Resistant Air Foam Compounds," T. Shimbashi (Tokyo Inst. Tech.), T. Izumi (U. of Tokyo), *Bull. Fire Prev. Soc.* **12**(2), 36, (1963) J, E

"Extinguishment of Fire by Water Spray(2)," Y. Yazi (U. of Tokyo), *Bull. Fire Prev. Soc.* **11**(1), 21, (1961) J, E

"Foaming Properties of Lime Hydrolyzate of Keratin Protein," T. Izumi (U. of Tokyo), *Bull. Fire Prev. Soc.* **10**(1), 21, (1961) J, E

Smoke

"Calculation of Smoke Movement in Buildings(2)," T. Wakamatsu (Build. Res. Inst.), *B.R.I. Res. Paper No. 46* (March 1971) E

"Calculation of Smoke Movement in Buildings," T. Wakamatsu (Build. Res. Inst.), *B.R.I. Res. Paper No. 34* (Aug. 1968) E

"Behavior of Smoke Flow and Smoke-Proofing of Escape Route," K. Fujita, T. Saga (Tohoku Inst. Tech.), *Bull. Fire Prev. Soc.* **19**(1), 1, (1969) J, E

"Smoke-Proof Tower by Means of Forced Heating," K. Nayuki, Y. Kuroda (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **19**(1), 35, (1969) J, E

"Model Experiment on Smoke Tower(3)," T. Maeda, T. Terai, S. Yamaguchi (U. of Kyoto), *Bull. Fire Prev. Soc.* **20**(2), 1, (1971) J, E

"Model Experiment on Smoke Tower(2)," T. Maeda, T. Terai, S. Yamaguchi (U. of Kyoto), *Bull. Fire Prev. Soc.* **20**(1), 31, (1970) J, E

"Model Experiment on Smoke Tower(1)," T. Maeda, T. Terai, S. Yamaguchi (U. of Kyoto), *Bull. Fire Prev. Soc.* **17**(2), 1, (1968) J, E

"Design of the Smoke Proof Tower," S. Hoshino (U. of Tokyo), *Bull. Fire Prev. Soc.* **17**(2), 35, (1968) J, E

"Visibility Through Fire Smoke(2)," T. Jin (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **21**(1), 17, (1971) J, E

"Visibility through Fire Smoke(2)," T. Jin (Fire Res. Inst.), *Report Fire Res. Inst. No. 33*, 31 (March 1971) E [*Fire Res. Abs. Rev.* **14**(2), 107]

"Visibility of Signs through Fire Smoke(1)," T. Jin (Fire Res. Inst.), *Trans. Architect. Inst. No. 182*, 21 (April 1971) J, E

"Visibility through Fire Smoke(1)," T. Jin (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **19**(2), 1, (1970) J, E
"Theoretical Interpretation on the Visibility through Aerosols(1)," T. Handa et al. (Tokyo Sci. College), *Bull. Fire Prev. Soc.* **17**(2), 11, (1968) J, E
"Smoke Generation from Organic Building Materials," F. Saito (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **18**(2), 9, (1969) J, E [*Fire Res. Abs. Rev.* **11**(3), 236]
"Smoke Generation from Building Materials," F. Saito (Build. Res. Inst.), *B.R.I. Res. Paper No. 33* (Aug. 1968) E

Physiological Problems

"Study on Injurious Properties of Combustion Products of Building Materials at Initial Stage of Fire," K. Kishitani (U. of Tokyo), *J. Faculty of Eng. U. of Tokyo* **31**(1), 1, (1971) E [*Fire Res. Abs. Rev.* **13**(3), 293]

Physical and Thermal Properties of Building Materials

"Fire Protective Properties of Aluminium Sash," M. Hamada (Tokyo Sci. College), *Bull. Fire Prev. Soc.* **16**(1), 21, (1966) J, E
"Fire Protectivity of Sandwich Panels," M. Hamada (Tokyo Sci. College), S. Hoshino (U. of Tokyo), *Bull. Fire Prev. Soc.* **12**(2), 51, (1963) J, E
"Ignition of Roof Shingles by Cigarette-Butts," M. Hamada, T. Wakamatsu (U. of Tokyo), *Bull. Fire Prev. Soc.* **11**(2), 40, (1961) J, E
"High Thermal Effect on Asbestos Cement Boards(1)," M. Mori (Asano Slate Co.), *Bull. Fire Prev. Soc.* **12**(2), 31, (1963) J, E
"Fire Resistance of High Tensile Bolted Friction Joints," M. Fujimoto (Tokyo Inst. Tech.), H. Hokugo (Electric. Telecom. Lab.), F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 184*, 17 (June 1971) J, E
"On the Fire Endurance of Curtain Walls," S. Hoshino (U. of Tokyo), *Bull. Fire Prev. Soc.* **13**(2), 36, (1965) J, E
"Fire Protection of Roofs and Eaves," S. Hoshino (U. of Tokyo), *Bull. Fire Prev. Soc.* **11**(1), 10, (1961) J, E
"Stress-Strain Relationship in Tension of Structural Steel at High Temperatures," T. Harada (Kanagawa U.), F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 185*, 1 (July 1971) J, E
"Fire Resistance of Steel Beam," H. Saito (Build. Res. Inst.), *B.R.I. Res. Paper No. 31* (March 1968) E
"Behavior of End Restrained Steel Members under Fire," H. Saito (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **15**(1), 7, (1966) J, E
"Theoretical Calculation of Temperature-Rise of Thermally Protected Steel Column Exposed to a Fire," S. Fujii (Build. Res. Inst.), *B.R.I. Occasional Report No. 10* (June 1963) E
"Theoretical Calculation of Temperature-Rise of Thermally Protected Steel Column Exposed to a Fire," S. Fujii (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **13**(1), 13, (1963) J, E
"Heat Flow Analysis of Building Members during Fire Exposure(2)," T. Wakamatsu (U. of Tokyo), *Trans. Architect. Inst. No. 111*, 31 (May 1965) J
"Heat Flow Analysis of Building Members during Fire Exposure(1)," T. Wakamatsu (U. of Tokyo), *Trans. Architect. Inst. No. 109*, 73 (March 1965) J, G

Thermal Properties of Concrete

"Thermal Stress of Reinforced Concrete Frames and Steel Frames in Fire," T. Harada (Kanagawa U.), F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 183*, 15 (May 1971) J, E

"Disturbance of Thermal Stress of Reinforced Concrete Members," F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 182*, 11 (April 1971) J

"Stress-Strain Relationship in Compression of Concrete at High Temperatures(3)," F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 174*, 1 (Aug. 1970) J, E

"Stress-Strain Relationship in Compression of Concrete at High Temperatures(2)," F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 173*, 17 (July 1970) J, E

"Stress-Strain Relationship in Compression of Concrete at High Temperatures(1): Apparatus and Test Procedure," F. Furumura (Tokyo Inst. Tech.), *Trans. Architect. Inst. No. 172*, 11 (June 1970) J, E

"Thermal Stress of Reinforced Concrete Frame in a Fire at a Tire Factory," T. Harada (Tokyo Inst. Tech.), K. Migita (U. of Kumamoto), T. Shiire and K. Shiina (Tokyo Inst. Tech.), *Bull. Fire Prev. Soc.* **12**(1), 6, (1962) J, E

"Decrease of Strength and Elasticity of a Reinforced Concrete Beam after Heating(2)," T. Harada (Tokyo Inst. Tech.), *Bull. Fire Prev. Soc.* **10**(1), 1, (1961) J, E

"Behavior of End Restrained Concrete Member in Fire," H. Saito (Build. Res. Inst.), *B.R.I. Res. Paper No. 32* (March 1968) E

"Explosive Spalling of Prestressed Concrete in Fire," H. Saito (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **15**(2), 23, (1966) J, E

"Explosive Spalling of Prestressed Concrete in Fire," H. Saito (Build. Res. Inst.), *B.R.I. Occasional Report No. 22* (June 1965) E

"Explosive Spalling of Artificial Lightweight Aggregate Concrete in Fire," M. Tamura (Mitsui Mining & Smelting Co.), *Bull. Fire Prev. Soc.* **16**(2), 1, (1967) J, E

"Effect of Specific Gravity on the Temperature Rise of Light Weight Concrete Exposed to a Fire," M. Hamada (Tokyo Sci. College), *Bull. Fire Prev. Soc.* **15**(1), 20, (1966) J, E

Building Fires

"Charts for Estimating the Equivalent Fire Duration on the Standard Temperature-Time Curve," K. Kawagoe (Build. Res. Inst.), *B.R.I. Res. Paper No. 45* (Jan. 1971) E

"Estimation of Fire Temperature-Time Curve in Rooms(3)," K. Kawagoe (Build. Res. Inst.), *B.R.I. Res. Paper No. 29* (Oct. 1967) E

"Estimation of Fire Temperature-Time Curve in Rooms(2)," K. Kawagoe, T. Sekine (Build. Res. Inst.), *B.R.I. Occasional Report No. 17* (March 1964) E

"Estimation of Fire Temperature-Time Curve in Rooms(1)," K. Kawagoe, T. Sekine (Build. Res. Inst.), *B.R.I. Occasional Report No. 11* (June 1963) E

"Estimation of Fire Temperature Rise Curves in Concrete Buildings and Its Application," K. Kawagoe, T. Sekine (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **13**(1), 1, (1963) J, E

"Calculation of Temperature in Double-Layer Walls Heated from One Side," K. Kawagoe (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **13**(2), 29, (1965) J, E

"Position of Neutral Layers in Upstairs and Downstairs When the Fire Is Burning in Both Floors," S. Yokoi (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **15**(2), 38, (1966) J, E

"Nature of High-Rise Building Fires(1): Analytical Approach to the Causes," K. Kamei (Nihon U.), *Bull. Fire Prev. Soc.* **17**(1), 11, (1967) J, E

Fire Tests

"Discussion on the Testing Method of the Fire Hazard of Organic Materials(2): Inclined Type Small Tunnel Furnace," T. Handa et al. (Tokyo Sci. College), Y. Ikeda and M. Saito (Adachi Plywood Co.), *Bull. Fire Prev. Soc.* **21**(1), 25, (1971) J, E

"Discussion on the Testing Method of the Fire Hazard of Organic Materials(1): JIS A1321 Furnace," H. Suzuki, T. Handa (Tokyo Sci. College), Y. Ikeda and M. Saito (Adachi Plywood Co.), *Bull. Fire Prev. Soc.* **21**(1), 1, (1971) J, E

"Surface Combustion of Organic Building Materials in Madison-Type Small Tunnel Furnace(2)," T. Handa, H. Suzuki (Tokyo Sci. College), M. Saito (Adachi Plywood Co.), *Bull. Fire Prev. Soc.* **17**(2), 25, (1968) J, E

"Surface Combustion of Organic Building Materials in Madison-Type Small Tunnel Furnace(1)," T. Handa et al. (Tokyo Sci. College), M. Saito (Adachi Plywood Co.), *Bull. Fire Prev. Soc.* **17**(1), 31, (1967) J, E

"Heat Transmission Relating to the Fire Endurance Test," T. Wakamatsu (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **17**(1), 43, (1967) J, E

"Report on the Full-Scale Fire Test in Yokohama," S. Yokoi et al. (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **14**(1, 2), 1, (1965) J, E

"Small Experimental Furnaces for the Fire Resistance Test of Various Building Materials," M. Hamada et al. (Committee on Small Experimental Furnace), *Bull. Fire Prev. Soc.* **11**(2), 32, (1961) J, E

"Evaluation of Fire Protectivity of Some Finishing Materials Used in a Simplified Fire Protective Construction," M. Hamada, S. Ikeda (U. of Tokyo), *Bull. Fire Prev. Soc.* **10**(1), 10, (1961) J, E

"Performance Test of Flame Proofing Materials(1)," S. Horiuchi, K. Akita, H. Arai (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **11**(2), 49, (1961) J, E

"Performance Test of Flame Proofing Materials(2)," S. Horiuchi, Y. Ota, K. Akita, H. Arai (Fire Res. Inst.), *Bull. Fire Prev. Soc.* **11**(2), 54, (1961) J, E

"Ignitability Test of Boards of Building Materials," S. Hoshino (U. of Tokyo), *Bull. Fire Prev. Soc.* **11**(2), 59, (1961) J, E

Mass Fires

"Equations for the Rate of Spreading of Fire," K. Yasuno (Japan Assoc. 1970 World Expo.), *Bull. Fire Prev. Soc.* **18**(1), 11, (1968) J, E

"How to Select Safety Zone in Tokyo in Case of Conflagration," M. Hamada (Tokyo Sci. College), *Bull. Fire Prev. Soc.* **17**(1), 25, (1967) J, E

"Fire Risk and Fire Control Schemes of Cities in Hokkaido(2)," M. Hamada (Tokyo Sci. College), K. Usui (Japan Housing Co.), Y. Isawa (Underwriters' Assoc.), T. Wakamatsu (U. of Tokyo), *Bull. Fire Prev. Soc.* **12**(1), 25, (1962) J, E

"Fire Risk and Fire Control Schemes of Cities in Hokkaido," M. Hamada (U. of Tokyo), Y. Isawa (Underwriters' Assoc.), K. Usui (Japan Housing Co.), *Bull. Fire Prev. Soc.* **11**(1), 13, (1961) J, E

"Nature of Conflagrations in Japan," K. Kamei (Underwriters' Assoc.), *Bull. Fire Prev. Soc.* **11**(1), 1, (1961) J, E

Fire Detectors

"Photoelectric Fire Detector Utilizing Flame Luminosity," Y. Tsutsui (Fire Res. Inst.), *Report Fire Res. Inst. No. 21*, 1 (March 1961) J, E

Miscellaneous

"Temperature Distribution on the Leeward of a Line Heat Source," S. Yokoi (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **13**(2), 49, (1965) J, E

"Upward Current from an Infinite Line Heat Source," S. Yokoi (Build. Res. Inst.), *Bull. Fire Prev. Soc.* **10**(1), 16, (1961) J, E

"Change of Insulation Properties of Vinyl Cord Covering by Heating," S. Soma, Y. Yawata, *Bull. Fire Prev. Soc.* **13**(2), 42, (1965) J, E

"Possible Danger in Mixing Barium Azide with Chloride Compounds," T. Kanasaka, K. Hirosawa (Tokyo Metro. Fire Board), *Bull. Fire Prev. Soc.* **11**(1), 7, (1961) J, E

"Ignition of a Sodium Piece in Air," K. Akita, S. Yamashika (Fire Res. Inst.), *Report Fire Res. Inst. No. 24*, 38 (March 1964) E

The author wishes to thank Dr. K. Nakata, the former Director of the Fire Research Institute of Japan, for supplying some information used in this bibliography.

ABSTRACTS AND REVIEWS

A. Prevention of Fires, Safety Measures, and Retardants

Alger, R. S. (Naval Ordnance Laboratory, Silver Spring, Maryland) **and Capener, E. L.** (Stanford Research Institute, Menlo Park, California) "Aircraft Ground Fire Suppression and Rescue Systems—Basic Relationships in Military Fires. Phases I and II," *AGFSRS-72-1, AFLC-Wright-Patterson Air Force Base, Ohio* (June 1972) See **Section E.**

Atallah, S. and Allan, D. S. (Arthur D. Little, Inc., Cambridge, Massachusetts) "Safe Separation Distances from Liquid Fuel Fires, *Fire Technology* **7**, 47–55 (1971)

Subjects: Safe separation distances; Liquid fires; Pool fires

Authors' Abstract and Recommendations

In question is the adequacy of the current method for calculating safe separation distances from large-scale liquid fuel fires. The authors point out the limitations and weaknesses of such calculations and recommend further research.

Recommendations

We believe that there is a definite need for large-scale spill fire tests employing a variety of liquid fuels. Data from these tests could be used to improve the assumptions made in calculating safe separation distances and to check theoretical predictions. In particular, we feel that the following areas need further investigation:

- The applicability of existing flame height correlations to large-size fires of varying spill shapes and fuels.
- Effective flame temperatures and their variation with flame height.
- Effect of wind on thermal radiation and geometry of large-scale fires.
- The contribution of soot clouds and radiation bursts to thermal radiation.

Coffee, R. D. (Eastman Kodak Company) "Evaluation of Chemical Stability," *Fire Technology* **7**, 37 (1971)

Subjects: Chemical stability, Stability of chemicals; Safety standards

Author's Summary

A system has been developed for establishing the relative potential of a chemical to release energy suddenly and to indicate the relative magnitude of that energy release. The system is based upon three simple tests requiring a minimum of sample (1 gram or 1 ml): 1) computation, 2) impact sensitivity, and 3) thermal stability. Sufficient examples have been provided to illustrate the development and use of the system. Although developed primarily for the preliminary classification of new chemicals, the system is suitable for reaction mixtures as well. The system may also find application in providing one factor of a general classification system for chemicals in transit or storage.

Economy, J., Wohrer, L. C., and Frechette, F. J. (Carborundum Company, Niagara Falls, New York) "Non-Flammable Phenolic Fibers," *J. Fire & Flammability* **3**, 114 (1972)

Subjects: Fibers, fabrics, nonflammable; Phenolic fibers

Authors' Abstract

To be useful for flame protection a fabric should neither melt nor burn in a flame and yet display comfort and wear features commonly associated with fibers used in wearing apparel. A new fiber based on a cross-linked phenol formaldehyde structure has been developed which satisfies these requirements. The properties of the phenolic fiber are discussed with particular emphasis on its behavior in a flame. Other properties which are described include mechanical behavior, moisture regain, corrosion resistance, and processing characteristics. Potential areas of use are indicated as well as results of blending with other fibers to improve their flame resistance.

Gipe, R. L. and Peterson, H. B. (Naval Research Laboratory, Washington, D.C.) "Proportioning Characteristics of Aqueous Film-Forming Foam Concentrates," *Naval Research Laboratory Report 7437* (July 20, 1972)

Subjects: Aqueous film-forming foam; Proportioning

Authors' Abstract

Aqueous Film-Forming Foam (AFFF) has now widely replaced protein-type foam in the Navy for fire suppression purposes. Because this changeover has been accompanied by very little change in the mechanical equipment, there has been a need to study the full impact of using AFFF in equipment designed for protein foam. One of the areas studied and covered in this report is concerned with the proportioning equipment used to inject foam concentrate into a fire main to form a 6% solution at fixed flow rates, variable flow rates, or both.

The early AFFF concentrates differ from the later ones in one physical property which affects their proportioning characteristics, i.e., viscosity. FC-194 and FC-195 brands of AFFF concentrates are more viscous (ca. 100 cS) than the protein foam concentrate (20 cS), while the new FC-196, FC-199, and FC-200 brands are less viscous (5 cS). Viscosity-temperature relationships are given for all these materials.

It was found that in certain types of proportioning equipment, such as nozzle eductors and simple orifices, solution strength is inversely related to viscosity so that lower viscosities produce higher solution concentrations. In other types of proportioning equipment in naval service, e.g., water-motor proportioners, an intermediate viscosity produces optimum results, and deviations to either higher or lower viscosities cause a reduction in solution concentration. By operating the equipment with a wide range of concentrate viscosities, it was possible to establish the proper viscosity for optimum operation as being between 20 and 80 cS.

Also studied were the use of booster pumps to supercharge the proportioner pump inlet and the use of positive displacement injection pumps for systems with fixed flows, such as the flush-deck nozzles on aircraft carrier flight decks. In the latter equipment, concentrate viscosity was found to a less critical factor in pump performance. Concentrate viscosity was found, however, to be a factor in setting the pump's internal pressure regulating valve.

Harmathy, T. Z. and Lie, T. T. (National Research Council of Canada, Ottawa, Ontario, Canada) "Experimental Verification of the Rule of Moisture Moment," *Fire Technology* 7, 17 (1971)

Subjects: Moisture moment; Fire endurance

Authors' Abstract

According to the "rule of moisture moment," the gain in fire endurance due to moisture is proportional to the moment of moisture about the exposed surface of the test specimen. The experimental results presented here confirm this suggestion.

Minne, R. and Vandevelde, P. (Department of Fire Research, State University at Ghent, Belgium) "Temperature Distribution in the Noncombustibility Furnace," *Fire Technology* **7**, 120–132 (1971)

Subjects: ISO-R 1182; Test methods

Authors' Abstract and Conclusions

The authors maintain that an ISO-recommended combustibility test for building materials contains weaknesses that may result in a material being classified "combustible" by one laboratory and "noncombustible" by another. They offer solutions to the shortcomings of the test.

Conclusions

The experimental work upon which this paper is based clearly shows that the thermal conditions of the ISO noncombustibility test furnace are insufficiently defined by the prescription of a conventional furnace temperature, t_f, of 750°C ±5°C (1382°F ±9°F). Theoretically, one solution to the problem could be to narrow the tolerance of ±1°C. Because of the difficulties in properly positioning the furnace thermocouple and maintaining the proper position throughout the test, this solution is of no practical use. Another possibility instead of the thermocouple would be to use a radiation pyrometer for calibration in the way described in this paper and to prescribe a furnace wall temperature distribution with a tolerance in ISO Recommendation R 1182.

The pyrometer calibration method has the advantages of being simple to perform and using uncomplicated equipment. The equipment is not very expensive, and it can be used practically indefinitely. It has excellent reproducibility and is sufficiently accurate.

The time required to perform the pyrometer method of calibration could be considered a disadvantage; however, there are several points that one must not forget. A thermocouple also has to be calibrated at regular intervals. A complete furnace calibration need not be done before each test, but only at regular intervals. A control thermocouple can be used during the warm-up period, so that a recording instrument will indicate when a thermal steady state is achieved. Only one check at a certain point of the furnace wall need be made with the pyrometer before each test. A considerable increase in the reproducibility of the heating conditions of the specimen will be obtained, so that the actual scattering of the test results must decrease.

One could say also that the pyrometer method gives no information about the thermal inertia of the furnace, which is true. However, when all the furnaces are made in the same way down to the smallest detail, there should be no problem as long as the furnace wall temperature distributions are the same everywhere. This, of course, means that ISO Recommendation R 1182 should be more explicit about construction details.

It has also been said that, if we add a pyrometer calibration and perhaps a thermal inertia calibration, the noncombustibility test is no longer a "simple" test. Such an argument cannot be accepted if one thinks of the interests that are at stake—the grading of a material as noncombustible or combustible.

Thomas, P. H. (Fire Research Station, Boreham Wood, Herts., England) "The Fire Resistance Required to Survive a Burn Out," *Fire Research Note No. 901, Joint Fire Research Organization* (November 1970)

Subjects: Fire resistance; Crib fires; Scaling

Author's Summary

A CIB research programme on the duration and temperatures of fully developed compartment fires has been completed. Data have been obtained for a wide variety of shapes, amounts and dispersion of fuel, scale and ventilation conditions. Estimates of the fire resistance t_f required to survive these fires have been made and are closely proportional to

$$L/(A_W A_T)^{1/2}$$

where L is the amount of fuel

A_W is the window area (or its equivalent)

A_T is the area of the internal surfaces over which heat is lost.

The constant of proportionality depends on the porosity of the fuel bed. Many published large scale experimental fires have also been examined and a similar law applies, but the constant of proportionality is somewhat less than those for the CIB experiments. The relationship between this form of t_f and Ingberg's correlation of fire resistance with fuel per unit floor area (L/A_F) is discussed, and it if suggested that Ingberg's correlation will over-estimate fire resistance requirements when

$$A_W A_T / A_F^2 > \tfrac{1}{3} \text{ approx.}$$

B. Ignition of Fires

Bowes, P. C. (Fire Research Station, Boreham Wood, Herts., England) and **Cameron, A.** (Norit-Clydesdale Co., Ltd., Glasgow, Scotland) "Self-Heating and Ignition of Chemically Activated Carbon," *J. Appl. Chem. Biotechnol.* 21, 244–50 (1971)

Subjects: Spontaneous ignition, Ignition, Self-heating; Carbon, activated

Authors' Abstract

Following the occurrence of fires in chemically activated carbon in transit, a study has been made of the self-heating and ignition properties of this material.

Thermal ignition theory has been applied to the results of laboratory scale self-ignition experiments and has enabled realistic prediction of critical sizes of pile for self-heating to ignition at ordinary ambient temperatures. However, predictions of times to ignition at ordinary temperatures are much larger than found in practice.

A distinction emerges between a long-term self-heating process responsible for the observed ignition of the "weathered" carbon and short-term processes which probably include the establishment of moisture equilibrium with the atmosphere and which are largely completed during the standard weathering time of eight days. The long-term process is not affected by this weathering but is dependent on the temperature of carbonization and weathering at elevated temperatures (e.g., 100°C). Safe carriage of the carbon in economically worthwhile quantities is ensured by packing in polyethylene bags. These can sustain a small amount of damage with impunity.

Freeston, W. D., Jr. (Fabric Research Laboratories, Inc., Dedham, Massachusetts) "Flammability and Heat Transfer Characteristics of Cotton, Nomex and PBI Fabric," *J. Fire & Flammability* **2**, 57 (January 1971) See **Section G.**

Palmer, K. N. and Butlin, R. N. (Department of the Environment, Fire Research Station, Boreham Wood, Herts., England) "Dust Explosibility Tests and their Application," *Powder Technology* **6**, 149 (1972) See **Section G.**

Smith, W. K. and King, J. B. (U. S. Naval Weapons Center, China Lake, California) "Surface Temperature of Materials during Radiant Heating to Ignition," *J. Fire & Flammability* **1**, 272 (1970)

Subjects: Surface temperature; Radiant ignition, Ignition

Authors' Abstract

Surface temperatures of nine organic combustible materials heated to flaming ignition by quartz lamp radiant heating equipment were measured without interference from reflected energy by means of a long wavelength infrared pyrometer. Temperature vs. time curves for irradiances from 0.125 to 2.5 cal/cm^2-sec are presented along with summary plots of surface temperatures at ignition for piloted and unpiloted ignition conditions. The factors influencing the shape of the curves and the initiation of ignition are discussed.

C. Detection of Fires

Lawson, D. I. (Joint Fire Research Organization, Boreham Wood, Herts., England) "A Laser Beam Fire Detection System," *Fire Technology* 6, 305 (1970)

Subjects: Laser fire detectors; Detector, laser; Fire detection by laser

Author's Abstract and Conclusions

With the use of mirrors, a single laser system can provide low-cost fire detection over large areas. In spite of the distances covered, reasonably constant sensitivity can be maintained throughout the protected area.

Conclusions

It should be possible to use the perturbations and absorption of a laser beam to provide a rapidly acting fire detector. The system should have an advantage over conventional systems in tall compartments due to the fact that the width of the spreading plume is used to detect fire; therefore, the decrease in sensitivity with height of the compartment to be protected is less marked than with other systems.

The laser beam has no inertia, and the delays are those of the rising plume of hot gas and smoke together with delays built into the system to prevent any adventitious alarm due to the beam being accidentally interrupted.

The cost of the system should be less than that of existing systems, and the problem of maintenance and testing should be much simpler than with individual detectors. A laser beam is unobtrusive and does not involve unsightly detectors. Moreover, it could be readily extended to give intruder protection. The cost of laser tubes has fallen rapidly recently, and it is thought that, commercially, the system should be capable of still further cost reduction.

O'Sullivan, E. F., Ghosh, B. K., and Turner, J. (Joint Fire Research Organization, Boreham Wood, Herts., England) "Experiments on the Use of a Laser Beam for Heat Detection," *Fire Technology* 7(2), 133–141 (1971)

Subjects: Laser fire detectors; Detector, laser; Fire detection by laser

Authors' Abstract and Conclusions

Earlier papers discussed the theory of using lasers for fire detection and described a system that was subsequently developed. The authors report on experiments with the system, which indicate that laser detection system performance is comparable with that of a heat-sensitive point detector of maximum sensitivity permitted by British Standard 3116.

Conclusions

The sensitivity to fire of a laser beam fire detection system has been studied. In this system, fire is detected by means of the time-varying deflections of the laser beam, which are caused by the hot combustion gases in turbulent flow beneath the ceiling. Frequency analyses of the output from the photocell on which the laser beam is incident have shown that fire can be be discriminated from other heat sources by selecting that part of the output of the photocell that is in the 40 to 80 Hz range.

Allowing a safe margin to avoid false alarms, a 140-kw fire at any position in a building 15 m by 41 m by 12 m high (50 ft by 135 ft by 40 ft high) can be detected in less than 45 sec. This performance compares very favorably with that of a rate-of-rise heat detector of the maximum sensitivity permitted in British Standard 3116.

D. Propagation of Fires

Freeston, W. D. Jr. (Fabric Research Laboratories, Inc., Dedham, Massachusetts) "Flammability and Heat Transfer Characteristics of Cotton, Nomex and PBI Fabric," *J. Fire & Flammability* 2, 57 (January 1971) See **Section G.**

Magee, R. S. and McAlevy, R. F., III (Stevens Institute of Technology, Hoboken, New Jersey) "The Mechanism of Flame Spread," *J. Fire & Flammability* **2**, 271 (1971)

Subjects: Fire spread; Fire propagation

Authors' Abstract

A number of factors influence flame spread rate, some in a way that results in large data scatter. The data reported in this paper were obtained using smooth-surfaced specimens with inhibited edges of reasonable scale in either vertically downward or horizontal propagating flames. Since the structure of the flame zone has never been studied, hypothesized models cannot be compared with any existing experimental evidence. As such, an impasse now exists which can be broken only if new studies concerning flame-zone structure are made.

E. Suppression of Fires

Alger, R. S. (Naval Ordnance Laboratory, Silver Spring, Maryland) **and Capener, E. L.** (Stanford Research Institute, Menlo Park, California) "Aircraft Ground Fire Suppression and Rescue Systems—Basic Relationships in Military Fires. Phases I and II," *AGFSRS-72-1, AFLC-Wright-Patterson Air Force Base, Ohio,* (June 1972)

Subjects: Aircraft ground fuel fires; Pool fires: radiation from, burning rate of, substrate influence on, wind effect on, geometry of, parameters for; Suppressant spray characterization; "Ideal" suppression; Standard test fires

Reviewed by R. L. Tuve

This report is the first of a projected series concerning some basic characteristics of hydrocarbon fuel fires and their extinction, especially those occurring during military operations. A very interesting dissection of Class-B fires and their illustrated "anatomies" from their geometrical and temporal development standpoints is given. Burning rates are discussed and the radiation field around a burning pool of jet fuel with and without wind is discussed at length. A few of the factors involved during the extinguishment process utilizing "light water" foams are pointed out, especially those relating to the recent U. S. Navy large-scale "CASS" tests at China Lake where flush-deck spray devices were used.

A series of small-scale modeling tests employing three-foot and ten-foot diameter fuel fires are described. Radiation measuring devices and light water spray head "Christmas tree" nozzle configurations were employed during these test fires. Test substrates included water, sand, and gravel. The solution suppressant spray was characterized as to uniformity, average drop size, and interaction kinetics with the fuel surface. Results showed that radiation fluxes at varying distances from the fire were affected by wind and velocity, location of the measuring station, and type of substrate and its water content. Suppression by AFFF foaming solution was found to be influenced primarily by the fire size and, secondly, by the type of substrate.

Alvares, N. J. and Lipska, A. E. (Stanford Research Institute, Menlo Park, California) "The Effect of Smoke on the Production and Stability of High-Expansion Foam," *J. Fire & Flammability* **3**, 88 (1972)

Subjects: Smoke; Foam; High-expansion foam; Stability of foam

Authors' Abstract

Combustion and pyrolysis products in the air supply of high-expansion foam generators generally inhibit foam production. This phenomenon is well documented, but the actual constituents of the products that inhibit foaming have not

been identified. The purpose of this research was to identify these foam-breaking constituents, for a broad class of fuels, and to determine the concentration of these compounds that would break foam.

In general, it was found that the pyrolysis products from both liquid and solid fuels were more efficient foam destroyers than were the combustion products. Fully half the number of constituents of the pyrolysis products that were tested were found to have a detrimental effect on foam production and/or stability; also, over 10 per cent of these were common to both liquid- and solid-fuel pyrolysis products. The concentrations of these constituents required to cause foam destruction were quite low, of the order of 10 to 100 parts per million.

Nash, P., Bridge, N. W., and Young, R. A. (Fire Research Station, Boreham Wood, Herts., England) "The Rapid Extinction of Fires in High-Racked Storages," *Fire Research Note No. 944, Joint Fire Research Organization* (August 1972)

Subjects: Fire extinguishing systems; Sprinkler; Storage

Authors' Summary

A quick-acting sprinkler system has been developed for the protection of racked storages. It consists essentially of a number of "zones" of open sprinkler heads, each zone of heads being each on the same vertical supply pipe which is fed from a horizontal main supply pipe on the opening of a valve. The valve is operated by a line detector distributed throughout the racking within the protected "zone," so that a fire starting within the zone brings the appropriate sprinklers into action. It has been shown experimentally that this system is very successful in detecting and controlling a fire during its very early stages, and some of the most difficult fires have been extinguished by it.

F. Fires, Damage and Salvage

Atallah, S. and Allan, D. S. (Arthur D. Little, Inc., Cambridge, Massachusetts) "Safe Separation Distances from Liquid Fuel Fires," *Fire Technology* **7**, 47–55 (1971) See **Section A.**

Minne, R. and Vandevelde, P. (Department of Fire Research, State University at Ghent, Belgium) "Temperature Distribution in the Noncombustibility Furnace," *Fire Technology* 7, 120–132 (1971) See **Section A.**

DeCicco, P. R., Cresci, R. J., and Correale, W. H. (Polytechnic Institute of Brooklyn, Brooklyn, New York) "Fire Tests, Analyses and Evaluation of Stair Pressurization and Exhaust in High-Rise Office Buildings," *Report No. 1, Center for Urban Environmental Studies, Polytechnic Institute of Brooklyn* (September 1972)

Subjects: Fire tests; High-rise buildings; Stair pressurization; Stack effect

Authors' Abstract

The test program was conducted in a 22-story office building at 30 Church Street in Manhattan and was carried out in three principal stages.

In the first stage, the supply and exhaust blower units were installed, tested and calibrated, leakage rates within the test stair shaft were measured and the time for pressurization was noted. The effects of open doors (various numbers and locations) were also observed.

In the second stage, pressurization conditions and conclusions established in stage one were examined and verified with the use of cold smoke. The ability of the system to prevent smoke from entering the stairwell was observed and conditions, with regard to opening of doors, which would cause the system to fail, were studied. Limited observations were also made of the effects of other vertical shafts on smoke movement. The feasibility of supplying air downward from the roof level in the pressurization of the stairwell was subjected to a limited test. The exhaust blower located on the roof was reversed and operated at maximum flow rate and cold smoke was used to observe the travel of gases through the building with the first floor door open and with one other door at an upper floor open.

In stage three, both smoke and heat were generated by four fires set at three different locations on the seventh and tenth floors. In addition to smoke, temperature, and pressure observations within the stairwell, measurements of smoke, temperature, and oxygen and carbon monoxide concentrations were made at other locations in the vicinity of the fire rooms, at more remote locations on the fire floors, and in lobby areas at several other floors.

During each of the actual fires, conditions in the test stairwell were also observed visually by officers of the New York City Fire Department and by members of the Polytechnic research team. Throughout the test program, other independent visual observations were made by representatives from the New York Board of Fire Underwriters, The Port Authority of New York and New Jersey and other interested agencies of the City, State and Federal Governments.

In general, the purpose of the first test was to verify the successful operation of the pressurization system under conditions of actual fire close to the stairwell, with substantial heat and smoke and possible elevated pressures.

Fires two and three were designed primarily to study the spread of smoke, heat and gases through ceiling areas. Fire test two was conducted with windows and doors closed and the air conditioning supply and exhaust systems inactive. Fire test three was conducted with the supply and exhaust system operating in an attempt to assess the rate and extent of spread of fire and products of combustion.

The fourth fire test was conducted in the same general location as test two and was planned to demonstrate the effectiveness of the roof exhaust unit, in conjunction with the fire compartments and stairwell, in the simulation of a smoke shaft system.

Hesleden, A. J. M., Theobald, C. R., and Bedford, G. K. (Fire Research Station, Boreham Wood, Herts., England) "Thermal Measurements on Unprotected Steel Columns Exposed to Wood and Petrol Fires," *Fire Prevention Science and Technology* **2**, 21 (1972)

Subjects: Heat transfer; Steel columns; Crib fires; Petrol fires

Authors' Conclusions

The experiments described in this note were carried out to give information on the temperature likely to be attained by an unprotected steel column exposed to a fire in the open or to a localized fire in a compartment. Temperatures attained by a column heated by wood and petrol fires are given. From the rate of temperature rise of the column and its dimensions and thermal capacity, rates of heat transfer to the column were obtained. The petrol fires gave higher rates of heat transfer and higher column temperatures. It is thought that the measurements reported will be of particular interest to designers of chemical plant. The results do not apply to situations where a fully-developed fire involves all the fuel in a compartment with a high fire load, nor where the confining effects of a compartment on a fire may be important; measurements of the temperature of unprotected steel in this last situation have been given by Butcher *et al.*

The Column

An unprotected I-section mild steel British Standard beam 200 mm × 150 mm (8 in. × 6 in.) in section, 2.1 m (7 ft) long, weighing 53 kg/m (35 lb/ft) was set up vertically to form a column in a large draft-free building and fires of wood sticks or petrol were burned at its base. The temperatures of the column, measured by means of thermocouples attached at 0.3 m intervals to both flanges and web, were recorded at 12-second intervals.

Wood Cribs

The wood sticks were square 40 or 20 mm in thickness, and were built into 1 m square cribs, weighing 29 kg, placed either symmetrically and closely round the column, or butted up against one size; the air space between both stick sizes was 40 mm. The cribs were ignited with strips of fiber insulating board soaked in kerosene so as to get the whole crib burning rapidly.

Petrol Trays

The petrol was floated on water in a number of steel trays arranged closely and symmetrically round the column to form a 1-m square. Three depths of petrol were burned (45, 17, and 5 mm), chosen to give:

a) the same fuel weight as one of the wood cribs;

b) the same total heat generated as a wood crib;

c) a fire of very short duration.

Experiments

The experiments are listed in Table 1. Flame height and duration of burning were noted for both wood and petrol fires. The temperature of the steel was recorded throughout the whole of the period of flaming and for some time after, to obtain cooling curves; wood embers were raked away as soon as flaming ceased so that they would not affect the cooling of the column.

The cribs of 40-mm-thick wood burned slowly and gave small flames so that the bottom of the column was heated more than the top. The cribs of 20-mm-thick wood and the two larger petrol fires burned more rapidly, producing flames taller than the column and heating it more evenly.

TABLE 1

Combustion, temperature and heat transfer data

Test No.	Fire	Maximum flame height	Duration of substantial burning*	Mean rate of burning	Mean rate of heat release†	Maximum temperature of any part of column	Time to reach maximum column temperature	Net heat transfer rate	Gross heat transfer rate
		m	min	kg/min	MW	°C	min	kW/m²	kW/m²
1	Wood crib (40mm sticks) round column	2.1	24	1.21	0.28	420	20	40	42
2	Wood crib (40mm sticks)	2.2	22	1.32	0.30	137	24	28	30
5	at side of column	1.8	22.5	1.29	0.30	137	28	24	24
3	Wood crib (20mm sticks)	3.3	13	2.23	0.51	505	8	35	39
4	round column	3.6	12	2.42	0.56	505	8	49	58
6	29 kg (9 gal) petrol round column	4.5	12	2.42	1.74	730	8	110	114
7	12 kg (3.5 gal) petrol round column	4.5	5.5	2.2	1.60	620	4	94	101
8	3.5 kg (1 gal) petrol round column	3.0	1.5	2.3	1.67	232	2	111	112

* Time for which flames were more than 0.3m high.
† Assuming calorific value of wood volatiles is 13.8 J/kg.

References

1. BUTCHER, E. G., BEDFORD, G. K., AND FARDELL, P. J. "Further Experiments on Temperatures Reached by Steel in Building Fires. Paper No. 1. Behaviour of Structural Steel in Fire," *Ministry of Technology and Fire Offices' Committee Symposium No. 2.* London, 1968.
2. HESLEDEN, A. J. M., THEOBALD, C. R., AND BEDFORD, G. K. "Thermal Measurements on Unprotected Steel Columns Exposed to Wood and Petrol Fires," *Joint Fire Research Organization Fire Research Note No. 874.*
3. BUTCHER, E. G., CHITTY, T. B., AND ASHTON, L. A. "The Temperature Attained by Steel in Building Fires," *Fire Research Technical Paper No. 15.* London, 1966.
4. RASBASH, D. J., ROGOWSKI, Z. W., AND STARK, G. W. V. "Properties of Fires of Liquids," *Fuel 35*(1), 94–107 (1956).
5. BEYREIS, J. R., MONSEN, H. W., AND ABBASI, A. F. "Properties of Wood Crib Flames," *Fire Technology 7*(2) 145–155 (1971).

Keough, J. J. (Commonwealth Experimental Building Station, Sydney, Australia) "Venting Fires through Roofs: Experimental Fires in an Aircraft Hangar," *Report No. UP 344, Commonwealth Experimental Building Station* (October 1972)

Subjects: Venting, fire, roof; Discharge coefficients; Tray fires; Fuel-spillage fires; Curtain boards

Author's Abstract

A statistically randomised series of tests was conducted in a disused aircraft hangar to obtain data for the design of automatic roof-venting systems for single-storey buildings of large floor area in which severe fires may develop rapidly as with fuel-spillage fires in aircraft hangars. Trays of AVTUR fuel were burned, and the interaction of four variables, namely fire area, roof-vent area, wall-inlet area, and depth of roof curtain, were investigated. Limited second and third series of tests were conducted to explore the effects, respectively, of reduction in roof height and of the simultaneous opening of all vents throughout the roof. The report details the relationships established.

Miller, C. F. (Defense Civil Preparedness Agency, Washington, D. C.) "Fire Fighting Operations in Hamburg, Germany, during World War II: Excerpts from the Hamburg Fire Department Documents on the Air Attacks during World War II, Appendixes 3, 4, 5, and Photographs," *Final Report under Contract No. DAHC20-70-C-0307 for Defense Civil Preparedness Agency* (April 1972)

Subjects: Fire; Fire fighting; Hamburg (Germany) fire damage in World War II

Author's Abstract

To obtain and preserve valuable untranslated records of the large fires resulting from air attacks in World War II, Defense Civil Preparedness Agency (formerly the Office of Civil Defense) sent Dr. Carl F. Miller and Mr. James W. Kerr to Germany in 1965. They found, and obtained permission to publish, a number of documents and photographs, particularly of the mass fire in Hamburg, Germany. These documents have been translated and analyzed, and a number of reports concerning them have been published. The present report contains the remaining translations and pictures considered worth preserving for those studying the effects of large fires.

Pearson, H. A., Davis, J. R., and Schubert, G. H. (Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona) "Effects of Wildfire on Timber and Forage Production in Arizona," *Journal of Range Management* **23**,(4), 250–253 (1972)

Subjects: Wildfire; Timber; Arizona; Ponderosa pine; Forest forage

Authors' Summary

A severe May wildfire decimated an unthinned ponderosa pine stand in northern Arizona, while an adjacent thinned stand was relatively undamaged. Radial growth increased on burned trees where crown kill was less than 60% and decreased where crown kill was more than 60%. Burning initially stimulated growth of herbaceous vegetation in both stands. Herbage nutrient value was temporarily enhanced due to burning. Artificially seeded areas produced most herbage two years after burning. Fire enhanced germination of Fendler ceanothus, a good wildlife species, and forb and grass production increased. Seeding the burn with orchard grass and intermediate wheat grass improved grass production significantly.

G. Combustion Engineering and Tests

Alvares , N. J. and Lipska, A. E. (Stanford Research Institute, Menlo Park, California) "The Effect of Smoke on the Production and Stability of High-Expansion Foam," *J. Fire & Flammability* **3**, 88 (1972) See **Section E**.

Batorewicz, W. and Hughes, K. A. (Uniroyal Chemical, Naugatuck, Connecticut) "The Application of the Oxygen Index to Urethane Foams," *J. Fire & Flammability* **2**, 260 (October 1971)

Subjects: Oxygen index; Urethane; Foams; ASTM D 1692

Authors' Abstract

The applicability of the Oxygen Index test to polyurethane foams was investigated. The precision of the test data was found to be close to that reported for noncellular plastics. The largest average deviation observed was 1.3% for rigid and 1.5% for flexible urethane foam samples. The test was quite sensitive, allowing for the relative order of activity of the additives tested to be clearly established. The results of the Oxygen Index test were compared with the data obtained from the ASTM D 1692 and the Bureau of Mines Flame Penetration test.

Bureau of Mines (U. S. Department of the Interior) "Methods for Evaluating Explosives and Hazardous Materials," *Bureau of Mines Information Circular 8541* (for sale by Superintendent of Documents, Government Printing Office, Washington, D.C. 20402) for 55 cents each (1972)

Subjects: Tests; Hazardous chemicals; Explosives

Summary

Methods and apparatus used by the Interior Department's Bureau of Mines for testing and evaluating explosives and hazardous chemicals are described in a new technical publication, now for sale by the Government Printing Office. The tests are used to evaluate sensitivity, strength, incendivity, gaseous products, and physical properties of explosives and hazardous chemicals. Tests that an explosive must pass for certification by the Bureau as "permissible" in underground coal mines are included. The Federal Coal Mine Health and Safety Act of 1969 specifies that U.S. coal mines may use only permissible explosives.

The new report will be valuable to manufacturers seeking permissibility classification for their products, as well as private firms and Government agencies interested in improving safety in mining and construction operations. Foreign governments (especially in developing nations) interested in establishing their own explosives safety programs have frequently requested information from the Bureau on subjects covered in the new report.

Sample preparation, apparatus, and test methods are described in the report, which contains photographs, diagrams, tables, and formulas used in calculations. A bibliography of 30 other reports on explosives testing is included.

Christian, W. J. (Underwriters' Laboratories, Inc., Northbrook, Illinois) **and Waterman, T. E.** (IIT Research Institute, Chicago, Illinois) "Ability of Small-Scale Tests to Predict Full-Scale Smoke Production," *Fire Technology* **7**(4), 332–334 (1971)

Subjects: Smoke tests; Smoke production; Scaling of smoke tests; IOD scale

Authors' Abstract and Conclusions

In testing the smoke production by interior finish materials, an attempt was made to correlate the results of a number of standard and nonstandard tests. Comparison of full-scale results and test results indicates that very limited correlation exists.

Conclusions

The data presented corroborate earlier findings that no single smoke rating number should be expected to define relative smoke hazards of materials in all situations. For the limited number of materials studied, it appears that the tunnel test data modified to report smoke developed in terms of integrated optical density may provide a useful measurement of smoke produced by interior finish materials in a corridor along which an exposing fire spread. More data are required to establish the extent of correlation between the test and full-scale fires, particularly for materials of tunnel smoke ratings between 1 and 3 on the IOD scale.

None of the test procedures examined adequately correlates with the smoke produced by finish materials totally engulfed in a fully developed room fire. The LRL chamber, which is a modification of the National Bureau of Standards smoke chamber, operated at nonflaming conditions is best in this respect. The inadequacies of all of the test methods studied in predicting smoke from room fire exposures seem to be concerned with their inability to produce the extremely heavy smoke associated with total involvement of some of the materials, particularly those of higher fuel content.

It seems reasonable to expect and seek out a judicious combination of results from tests under two or more widely differing exposures that will provide the basis for a rating system that adequately accounts for the effects of material location, fire intensity, and other factors for materials totally engulfed by a room fire.

DiPietro, J. and Stepniczka, H. (Michigan Chemical Corporation, St. Louis, Michigan) "A Study of Smoke Density and Oxygen Index of Polystyrene, ABS and Polyester Systems," *J. Fire & Flammability* **2**, 36 (January 1971)

Subjects: Smoke density; Oxygen index; ABS; Polystyrene; Polyesters; Flammability; Retardants

Authors' Abstract

The influence of temperature upon the flammability of flame-retarded and untreated polymeric systems was determined employing the Oxygen Index Method.

When polymers are exposed to a radiant heat source, their Oxygen Indices generally decrease—the degree of increasing flammability depends upon the polymeric system itself and the type of flame retardants used as well.

The density of smoke generated by the burning polymers was also measured. A faster smoke build-up can be found for flame-retarded systems than for untreated ones. The gross amount of smoke generated by treated systems, however, is smaller than that of untreated polymers because the untreated ones burn until they are consumed while flame-retarded systems form a char on the burning surface and extinguish shortly thereafter. This was found to be true at room temperature and at elevated temperatures as well.

Comparative DSC and TGA analyses supplied information about the thermal behavior and decomposition ranges of the polymers used in this study.

Engerman, H. S. (Underwriters' Laboratories, Inc., Northbrook, Illinois) "Floor Covering Systems—A Test for Flame Propagation Index," *J. Fire & Flammability* 2, 11 (January 1971)

Subjects: Flooring; Floor coverings, carpets; Flame propagation; Sustained flaming; Classification; Fire tests

Author's Abstract

A test method has been developed for the measurement of the flame-propagating characteristics of flooring and floor covering materials. In the evolution of the test equipment and the testing procedure, consideration was given to the potential fire hazards created by flooring and floor covering materials and the effect of various ignition sources on the performance of these materials in a fire situation. Four ignition sources were explored: a continuous flame exposure, an intermittent flame exposure, a burning wood crib exposure, and a glowing charcoal briquet exposure. A continuously applied test flame was the ignition source that provided measurements most representative of the potential for flame propagation on flooring and floor covering materials. Tests were conducted on a variety of commercial (low pile) and residential (plush and shag) carpetings, with and without various underlayments, several resilient floor coverings, and wood flooring materials. The results are reported on the basis of observations of (1) the extent of flame propagation during the application of the test flame, (2) the time of propagation, (3) the extent of flame propagation (interpreted as sustained ignition) after extinguishment of the test flame, and (4) the duration of sustained flaming after extinguishment of the test flame (within a specified observation period). The findings of the study substantiate the suitability of the test method to measure the propagation of flame over flooring and floor covering materials consisting of systems of coverings, underlayments and substrates having different insulation and combustion properties. The results are subsequently classified into ranges describing limits of performance.

Finley, E. L. (Department of Home Economics, Louisiana State University, Baton Rouge, Louisiana) **and Carter, W. H.** (Department of Agricultural Engineering, Louisiana State University, Baton Rouge, Louisiana) "Temperature and Heat-Flux Measurements on Life-Size Garments Ignited by Flame Contact," *J. Fire & Flammability* **2**, 298 (October 1971)

Subjects: Temperature measurements; Heat flux measurements; Garment fires; Ignition of fabrics

Authors' Abstract

A life-size, fireproof mannequin or torso-form has been used to test a garment of a single thickness of fabric made of selected cotton, and cotton-polyester blend fabrics, with no finish, and treated with APO—THPC, THPOH–MM–Urea, and THPOH—NH_3 finishes. Flame from Bunsen type burners was impinged on the garment at the hem edge. Surface heat and flame temperature of fabrics which ignited were measured at thermocouple sites located on the torso-form.

Fox, M. D. (Rolls Royce, Ltd., Bristol, England) **and Weinberg, F. J.** (Department of Chemical Engineering and Chemical Technology, Imperial College, London, England) "Measurement of Flame Area in Terms of Saturation Current," *Thirteenth Symposium on Combustion*, the Combustion Institute, Pittsburgh, Pennsylvania, p. 641 (1971)

Subjects: Flame areas; Saturation current; Burning velocity

Authors' Abstract

A new method for determining the area A of premixed flames is presented, based on measuring the saturation current J_s. (J_s/A), the saturation-current density, is the total rate of ion generation per unit area of front—a constant for each initial composition and state of the mixture. The limitations of the method due to space charge are discussed. Measurements are then carried out on steady, fluctuating, turbulent, and expanding flame fronts.

It is confirmed for laminar flames of various shapes that, for each particular mixture, the saturation current is basically proportional to volumetric flow rate, except as modified by entrainment. Transition from laminar to trubulent flow destroys this linearity suddenly and discontinuously. This differs from the behavior of flames which oscillate as a whole, and is discussed in terms of the "wrinkled-flame-front" hypothesis of turbulent burning. The method is found to have adequate

time resolution to record transient fluctuations in turbulent flames. The principle is also applied to expanding flame surfaces following ignition and is shown to provide a new method of measuring burning velocity in this form.

Freeston, W. D. Jr. (Fabric Research Laboratories, Inc., Dedham, Massachusetts) "Flammability and Heat Transfer Characteristics of Cotton, Nomex and PBI Fabric," *J. Fire & Flammability* **2**, 57 (January 1971)

Subjects: Flammability; Heat transfer; Cotton; Nomex; PBI; Fabrics; Ignition temperature; Burning rate

Author's Abstract

The ignition temperatures and burning rates in air of similar PBI, Nomex and flame-retardant-treated cotton fabrics are given, and the thermal shrinkage of PBI and Nomex fabric are compared. The thermal conductivity of a series of fabrics at ambient and elevated temperatures is given. The temperature rise in a fabric-covered skin simulant under flame impingement is investigated for a range of fabric constructions. The flame-impingement heat-transfer experimental data are compared with theoretically predicted results. A parametric study of the material properties which govern heat transfer through a fabric under flame impingement is presented. The results indicate that one type of fibrous structure which will provide improved thermal protection is moderate weight, tightly woven PBI fabric over a PBI tricot mesh.

Hendrix, J. E., Beninate, J. V., Drake, G. L., Jr., and Reeves, W. A. (Southern Regional Research Laboratory, U. S. Department of Agriculture, New Orleans, Louisiana) "Environmental Temperatures and Oxygen Index (OI) Values for Textile Fabrics," *J. Fire & Flammability* **3**, 2–18 (January 1972)

Subjects: Oxygen index; Textiles; Fabrics; DTA; TGA; Thermal analysis

Authors' Abstract

The flammability properties of selected natural, synthetic, and blended textile fabrics were investigated using the OI technique. Environmental temperatures during testing were varied over the −50 C to 260 C range. Under conditions of controlled environmental temperatures, thermal activities within the samples or

interactions of the samples with oxidizing atmospheres cause variations in OI values. DTA and TGA thermograms of the samples in oxidizing atmospheres illustrate these thermal interactions and activities, and constitute a basis for explanation of the origin of the observed OI variations.

Palmer, K. N. and Butlin, R. N. (Department of the Environment, Fire Research Station, Boreham Wood, Herts., England) "Dust Explosibility Tests and their Application," *Powder Technology* **6**, 149 (1972)

Subjects: Dust; Explosibility; Powders; Tests; Ignition

Authors' Summary

A description is given of the current test methods for the classification of dusts according to explosibility and, for explosible dusts, measurement of the minimum ignition temperature, minimum ignition energy, minimum explosible concentration, maximum explosion pressure and rate of pressure rise, and the maximum permissible oxygen concentration to prevent ignition of a dust cloud.

The application of these tests to industrial processes is discussed and their limitations are surveyed in the context of the lack of background information on dust explosions.

Further information is urgently needed on the mechanism whereby flame propagates from one dust particle to another in a dust explosion. Current work at the Fire Research Station on this topic is outlined.

Romodanova, L. D., Mal'tsev, V. M., and Pokhil, P. F. (Moscow, U.S.S.R.) "Effect of the Physicochemical Properties of a Fuel and Oxidizer on the Nature of the Dependence of the Burning Rate of the Mixture Composition in the Degree of Dispersion of the Fuel," *Fizika Goreniya i Vzryva* **8**, 9 (1972)

Subjects: Burning rate; Dispersion and burning composition

Authors' Conclusions translated by L. Holtschlag

Stoichimetric compositions of various tabulated oxidizers and fuels were pressed in a mold to maximum density and ignited in a bomb in a nitrogen atmosphere. The burning rate was measured by photography. The size of the oxidizer particles was less than 100μ; two fuel fractions were used: (1) 50–63μ and (2) 230–314μ.

The burning process was photographed. The surface temperature of the compositions was measured by the "sapphire light conductor" method. The study showed that in the case of a fusible oxidizer and a nonvolatile fuel, the burning rate of a mixture with a highly dispersed fuel is much greater than that of one weakly dispersed. Apparently, the heat transfer from the combustion zone to the fresh material in the presence of a liquid layer is very important during the burning process. It is easier through large crystals than through small ones. In the case of a large grain, the possibility of penetration of hot gases and liquid reaction products into the pores is probably greater than in the case of a small grain, but this is no longer true when the liquid layer is dispersed. Consequently, a liquid layer on the surface of the charge influences the dependence of the burning rate on the pressure, initial temperature, and the degree of dispersion of the components.

H. Chemical Aspects of Fires

Beall, F. C. (Pennsylvania State University, University Park, Pennsylvania) "Differential Calorimetric Analysis of Wood and Wood Components," *Forest Products Laboratory, U. S. Department of Agriculture, Madison, Wisconsin* and *Wood Science and Technology* **5,** 159–175 (1971)

Subjects: Calorimetry; Pyrolysis; Heat of reaction; Wood

Author's Summary

The pyrolysis of cellulose, hemicelluloses, lignin preparations, and wood was studied by differential calorimetric analysis (DCA) for the range of 25° to 800°C. The test samples included powdered and filter paper celluloses; hardwood xylan; softwood galactoglucomannans, compression wood galactan, and arabinogalactan; a synthetic (DHP), sulfuric acid, Björkman, Brownell, and cellulase lignins; and unextracted and extracted hardwoods and softwoods. Heats of reaction were determined from the DCA thermal transition areas. Distinct differences were found between the thermograms of each hemicellulose and lignin sample. Although wood species could not be separated thermally, hardwood and softwood thermograms differed because of the hemicellulose degradation pattern.

Bowes, P. C. (Fire Research Station, Boreham Wood, Herts., England) **and Cameron, A.** (Norit-Clydesdale Co., Ltd., Glasgow, Scotland) "Self-Heating and Ignition of Chemically Activated Carbon," *J. Appl. Chem. Biotechnol.* **21,** 244–250 (1971) See **Section B.**

Fung, D. P. C., Tsuchiya, Y., and Sumi, K. (National Research Council of Canada, Ottawa, Canada) "Thermal Degradation of Cellulose and Levoglucosan—The Effect of Inorganic Salts," *Research Paper No. 545, Division of Building Research, National Research Council of Canada, Ottawa, Canada* (November 1972)

Subjects: Thermal degradation; Cellulose; Pyrolysis; Retardants

Authors' Summary

The effects of eleven inorganic flame retardants on the flammability of cellulose have been investigated, and these flammability data were compared with the tar (levoglucosan) formation from the pyrolysis process. There was no correlation between the effectiveness of these flame retardants as determined by a minimum oxygen concentration flammability test at 1 per cent treatment level and the amount of levoglucosan formed. This finding is contrary to the suggestions made by previous workers. A study of the pyrolysis of levoglucosan in the presence of potassium bromide (neutral), potassium carbonate (basic), and phosphoric acid (acidic) was made. Phosphoric acid had the most pronounced effect on the breakdown of levoglucosan; and carbon monoxide, carbon dioxide, water, and residual char were among the major products. The data from the DP study indicate that both basic and acidic additives, sodium tetraborate decahydrate, and ammonium monohydrogen orthophosphate, accelerate the depolymerization in the early stages of the pyrolysis of cellulose.

Woolley, W. D. and Wadley, A. I. (Fire Research Station, Boreham Wood, Herts., England) "The Production of Free Tolylene Diisocyanate from the Thermal and Thermal-Oxidative Decomposition of Flexible Polyurethane Foams," *Fire Research Note No. 947, Joint Fire Research Organization* (October 1972)

Subjects: Gas chromatography; Mass spectrometry; Polyurethane foam; Pyrolysis; Tolylene diisocyanate; Toxic gas

Authors' Summary

The production of free TDI from the thermal and thermal oxidative decomposition of polyester and polyether flexible polyurethane foams has been monitored at temperatures between 200 and 800°C. The decompositions were undertaken in an all-glass system and the TDI collected in dry toluene and analysed by gas chromatography and mass spectrometry. The polyester foam releases a maximum of 1.1 and 1.15 weight per cent of TDI in nitrogen and air atmospheres, respectively, whereas the polyether foam generates, respectively, 0.9 and 0.7 weight per cent. These maximum yields are recorded at the relatively low temperatures of 250 to 300°C. At temperatures above about 800°C in nitrogen and 700°C in air, TDI is completely destroyed in the decomposition apparatus.

Realistic fire tests involving TDI based flexible foams are required in order to evaluate the hazard of free TDI in real fire situations. Additional information on the toxic effects of TDI may be required for this appraisal.

Woolley, W. D. (Fire Research Station, Boreham Wood, Herts., England) "Studies in the Dehydrochlorination of PVC in Nitrogen and Air," *Plastics and Polymers* **40**, 203–208 (1972)

Subjects: PVC, Polyvinyl chloride; Pyrolysis; Dehydrochlorination; Corrosion; Kinetics

Author's Abstract

When involved in fires PVC releases the toxic and corrosive gas hydrogen chloride. Samples of a commercial PVC were heated at temperatures between 200° and 300°C in a flow of nitrogen or air and the total hydrogen chloride was monitored as a function of time. In each atmosphere the dehydrochlorination conformed to a 3/2-order decomposition based upon the concentration of residual hydrogen chloride in the PVC. The integrated form of the rate equation is $(100-P)^{-1/2}=0.1+\frac{1}{2}kt$ where P is the released hydrogen chloride as a percentage of the theoretical, k is the rate constant and t is the decomposition time. The relationship is valid to 80% of theoretical dehydrochlorination in nitrogen and 70% in air. Arrhenius plots gave $\log_{10} k=15.27—9.13\times10^3\ (1/T)$ for nitrogen (activation energy 174 kJ/mol) and $\log_{10} k=12.93—7.86\times10^3\ (1/T)$ for air (activation energy 151 kJ/mol) where T is the temperature in degrees absolute.

The data have been used to calculate the times for dehydrochlorination at isothermal temperatures between 200° and 300°C. At 200°C, 50% of theoretical dehydrochlorination is attained in 882 min in nitrogen (403 min in air) which is reduced to 0.38 min at 300°C (0.51 min in air). During non-linear temperature increments, as in fires, dehydrochlorination is calculated by summing a series of isothermal intervals which represent approximately the temperature/time variation of the PVC.

Woolley, W. D., Wadley, A. I., and Field, P. (Fire Research Station, Boreham Wood, Herts., England) "Studies of the Thermal Decomposition of Flexible Polyurethane Foams in Air," *Fire Research Note No. 951, Joint Fire Research Organization* (November 1972)

Subjects: Gas chromatography; Polyurethane foam; Pyrolysis; Toxic gas

Authors' Summary

The thermal decomposition of various polyester and polyether flexible polyurethane foams has been carried out in air atmospheres between 300 and 1000°C. It is shown that the main decomposition processes are similar to those observed in inert atmospheres, namely that the decomposition proceeds via the initial release (200 to 300°C) of a nitrogen-rich material which subsequently decomposes at temperatures above about 500°C (800°C in inert atmospheres) to give nitrogen-containing materials of low molecular weight, particularly hydrogen cyanide,

acetonitrile, acrylonitrile and benzonitrile. The intermediate nitrogen-rich material has not been directly isolated from oxidative environments, but the experiments of this report indicate that it is probably identical to the 'yellow smoke' observed under inert conditions. The main nitrogen-containing material observed in this work produced from the thermal-oxidative decomposition of the intermediate is hydrogen cyanide of which the yield increases with temperature from 500 up to 700°C, decreases at 800°C, then increases again at 900 and 1000°C. At 700°C approximately 10 to 20 per cent of the theoretically available nitrogen is released as hydrogen cyanide, and at 1000°C this figure rises to 35 to 40 per cent of the theoretical.

I. Physical Aspects of Fires

Havens, J. A. (University of Arkansas, Fayetteville, Arkansas), **Welker, J. R.** and **Sliepcevich, C. M.** (University of Oklahoma, Norman, Oklahoma) "Pyrolysis of Wood: A Thermoanalytical Study," *J. Fire & Flammability* **2**, 321 (October 1971)

Subjects: Pyrolysis, wood; Thermoanalysis; Energy capacity; TGA

Authors' Abstract

The "energy capacity" of dry wood, which includes both sensible heat and decomposition heat effects, has been measured using a differential scanning calorimetric technique. The "energy capacity" data for thermal decomposition of dry pine and oak woods in nitrogen show that the net internal heat effect due to decomposition is endothermic. The decomposition heat effects show good correlation with thermal gravimetric and differential thermal gravimetric data taken in this study. Thermal gravimetric analyses were made with heating rates varying from 20 C/min to 160 C/min and the results indicate that for such rates the application of a heat transfer-thermal decomposition model which neglects dependence on rate of heating is defensible.

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Visibility through Fire Smoke," *Bulletin of the Fire Prevention Society of Japan* **19**(2), 1 (1970)

Subjects: Smoke; Visibility

Review by Y. Tsuchiya

Visibility of signs through fire smoke has practical importance in connection with evacuation from fires. Visibility depends not only on smoke density but also on the characteristics of smoke, brightness of signs, and the conditions of illumination. From a consideration of light scattering the author theoretically derived an equation for visible distance of a sign. That is,

$$\sigma V = \log_e(B/\delta k L) \qquad (1)$$

where V is visible distance; σ, extinction coefficient in Beer-Lambert law (which is an indication of the concentration of smoke); δ, threshold brightness contrast of signs and background, which was found experimentally to be about 0.01; L, intensity of external light; k, ratio of light scattering coefficient and extinction coefficient of smoke. The ratio k is given by the equation,

$$k = \sigma_{s/\sigma} \qquad (2)$$

where σ_s is scattering coefficient. $k=1$ for nearly white smoke.

The author verified the equation (1) by his experiments in which reflection-type and luminous-type signs were tested at distances of 5.5 m, 10.5 m and 15.5 m in a white smoke which was produced by smoldering paper. The extinction coefficient ranged from 0.4 to 1.8 m^{-1}. The dimensionless number σV in equation (1) depends on B/L. For the best reflection-type sign, σV was about 4. For the luminous-type, σV theoretically has no limit, but practical maximum was about 10.

Neill, D. T. (Idaho State University, Pocatello, Idaho), **Welker, J. R.**, and **Sliepcevich, C. M.** (University of Oklahoma Research Institute, Norman, Oklahoma) "Direct Contact Heat Transfer from Buoyant Diffusion Flames," *J. Fire & Flammability* **1**, 289 (October 1970)

Subjects: Heat transfer; Diffusion flames; Convective heat flux; Radiative heat flux

Authors' Abstract

A knowledge of the direct contact heat transfer rate to an object surrounded by fire is fundamental to fire protection. Heat transfer by direct flame contact is due to both convection and radiation, but these two mechanisms do not scale simultaneously. A technique was devised to measure both the convective and radiative heat fluxes from a flame. The resulting data can be used to predict the heat transfer rate for fires in contact with cooler objects.

J. Meteorological Aspects of Fires

Sando, R. W. and Haines, D. A. (North Central Forestry Experiment Station, USDA, St. Paul, Minnesota) "Fire Weather and Behavior of the Little Sioux Fire," *U. S. Department of Agriculture Forest Service Research Paper NC-76* (1972)

Subjects: Fire control; Crowning; Spot fires; Fire danger; Superior National Forest; Boundary Waters Canoe Area

Authors' Abstract

In mid-May 1971, a northern Minnesota fire burned almost 15,000 acres of forest land. The extreme fire behavior it exhibited was the product of a number of described features. This paper documents the attendant fuel and weather conditions.

K. Physiological and Psychological Problems from Fires

Woolley, W. D. (Joint Fire Research Organization, Boreham Wood, Herts., England) "Studies of the Dehydrochlorination of PVC in Nitrogen and Air," *Plastics and Polymers* **40**, 203–208 (1972) See **Section H.**

Yuill, C. H. (Southwest Research Institute, San Antonio, Texas) "The Life Hazard of Bedding and Upholstery Fires," *J. Fire & Flammability* **1**, 312 (October 1970) (Article based on final report of program sponsored by Fabric Flammability Section, National Bureau of Standards, entitled "Characterization of Bedding and Upholstery Fires," dated March 31, 1970)

Subjects: Life hazards; Bedding; Upholstery fires; Smoke; Toxic gases

Author's Abstract

Many accidental deaths are attributed to fires started from smoking in bed or in upholstered chairs. Frequently, the victims die as a result of exposure to smoke, heat, or noxious fumes that develop as materials burn rather than from skin burns. The objective this program was to conduct full-scale tests using bedding and upholstered furniture to determine the life hazards that may be present during fires starting with a small ignition source.

Thirty individual tests were conducted using various combinations of materials. The ease of ignition of bedding and upholstery was demonstrated and the pattern of development of smoke, heat, noxious gases, and oxygen depletion was recorded.

L. Operations Research, Mathematical Methods, and Statistics

Chandler, S. E. and Woolley, J. E. (Fire Research Station, Boreham Wood, Herts., England) "Fire Deaths in the Third Quarter of 1971," *Fire Research Note. No. 902, Joint Fire Research Organization* (November 1971)

Subjects: Deaths; Fire casualties

Authors' Summary

A preliminary analysis shows that 83 persons died in fires in the period July to September 1971. Of these, 74 were in England and Wales and 9 in Scotland. An unstated number of fatalities occurred in one incident reported from Northern Ireland.

The most serious incident reported in the quarter was a crash on the M6, giving rise to six fire deaths.

Chandler, S. E. (Joint Fire Research Organization, Boreham Woods, Herts., England) "Preliminary Analysis of Fire Reports from Fire Brigades in the United Kingdom, 1971," *Fire Research Note No. 935, Joint Fire Research Organization* (May 1972)

Subjects: Fire statistics; Casualties

Author's Summary

A preliminary analysis shows that there were 253,535 fires attended by fire brigades in the United Kingdom in 1971. Fatal casualties numbered 782, of which three were fire brigade personnel; the number of non-fatal casualties was 4,883. The estimated direct financial loss due to fire was £128.7 M, the highest ever recorded figure.

Eggleston, L. A. (Southwest Research Institute, San Antonio, Texas) "Fire Defense Systems Analysis," *Southwest Research Institute Project 03-2550 under Contract DAHC20-70-C-0210 for Office of Civil Defense* (Defense Civil Preparedness Agency) (October 1970)

Subjects: Fire defense; Nuclear attack conditions; Urbanized area; Peacetime defense elements; Thermal hardening

Author's Abstract

A hypothetical, but not infeasible, fire defense system for a metropolitan area under nuclear attack conditions, developed in an earlier study, is examined for operability in an assumed situation at San Jose, California. The analysis concluded that with thermal hardening and citizen self-help, the system would be effective and the consequences of the attack would be minimal. Additional refinements for the basic system were developed during the study.

Melinek, S. J. (Fire Research Station, Boreham Wood, Herts., England) "A Method of Evaluating Human Life for Economic Purposes," *Fire Research Note No. 950, Joint Fire Research Organization* (November 1972)

Subjects: Life, monetary value of; Risk, perceived

Author's Abstract

A method of estimating a monetary value of life which can be used for the evaluation of safety precautions is presented. People are willing to spend money to reduce the risk of accidents, or to increase the risk for some benefit, and this method endeavours to estimate the value of life which is consistent with their behaviour. Examples of the application of this method are given which indicate that the value of a life is of the order of £50 000. The results obtained are compared with values given by discounted earnings. The evaluation of future risks and the importance of perceived risk are also considered. Factors influencing perceived risk are discussed.

Miller, C. F. (Defense Civil Preparedness Agency, Washington, D. C.) "Fire Fighting Operations in Hamburg, Germany, during World War II: Excerpts from the Hamburg Fire Department Documents on the Air Attacks during World War II, Appendixes 3, 4, 5 and Photographs," *Final Report, Defense Civil Preparedness Agency* (April 1972) See **Section F.**

North, M. A. and Baldwin, R. (Fire Research Station, Boreham Wood, Herts., England) "Some Statistics of Fires in Shops and Their Application to Town Centre Developments," *Fire Research Note No. 946, Joint Fire Research Organization* (September 1972)

Subject: Fire statistics

Authors' Summary

The statistics of fires in shops are studied with a view to assessing fire hazards in shopping malls. It is estimated that, in a 200-shop mall, a fire would be expected most years on average and a large-loss fire every 30 years. The latter figure might be reduced to five years if shopping malls behave similarly to department stores.

One-quarter of the shop fires originated in cooking appliances, mainly deep-fat frying ranges, and shops using these appliances would merit special attention to fire prevention or protection. Good housekeeping and frequent refuse disposal would also reduce the number of fires. It appears that sprinkler systems reduce the number of fires attended by fire brigades by a factor of 2 or 3. The probability of failure of sprinkler systems in shops is estimated as 0.065 to 0.09.

O'Hara, I. B. and Lewis, S. A. (Joint Fire Research Organization, Boreham Wood, Herts., England) "Fires in Buses, Coaches and Mini Buses," *Fire Research Note No. 936, Joint Fire Research Organization* (June 1972)

Subjects: Fire statistics; Vehicles

Authors' Summary

The number of fires in buses, coaches and mini buses reported by fire brigades in the United Kingdom increased from 190 in 1964 to 562 in 1969 (58 fires in mini buses in 1969). Fires in Great Britain per thousand buses, coaches and mini buses licenced increased from 2.5 in 1964 to 7.1 in 1969.

The most common single supposed cause is the ignition of wire and cable due to short circuits. Mechanical heat in its various forms, however, is the most commonly reported group of causes.

Fifty-eight per cent of the fires start in the engine of the vehicle, 15 per cent inside the vehicle, 15 per cent in the wheels.

Eighty-six per cent of the fires occur when the vehicle is on the road.

The greatest number of fires in buses occur during the 'rush' hours.

There are more fires in the summer months in buses, coaches and mini buses, although in mini buses the peak is much less marked than in the other two classes of vehicle.

Age of the vehicle does not appear to be an important factor in connexion with the outbreak of fire.

Sixty-per cent of the fires are tackled before arrival of the Brigade though only 35 per cent of these are successfully extinguished.

There were no fatal casualties in fires in buses, coaches and mini buses, and the estimated number of non-fatal casualties was only six in six incidents during 1969.

Silcock, A., Theobald, C. R., and Daxon, W. N. (Fire Research Station, Boreham Wood, Herts., England) "The Survey of Fires in Buildings. Fire Survey Group. 2nd Report—Industrial Fires," *Fire Research Note 948, Joint Fire Research Organization* (October 1972)

Subjects: Fire spread; Building fires

Authors' Summary

The first report of results of the pilot exercise in fire surveying set out the nature of information obtainable from such surveys and gave a preliminary analysis of the nineteen house fires surveyed by the date of issue.

This second report presents and discusses an analysis of information from 40 industrial fires.

There are admittedly too few observations of any one feature for firm conclusions to be drawn, but typical of points of interest are observations relating to downward spread of fire through timber floors, and the marked effect of the direction of air currents around the edge of a timber door on its fire resistance.

Theobald, C. R. (Fire Research Station, Boreham Wood, Herts., England) "The Effect of Roof Construction and Contents on Fires in Single-Storey Buildings," *Fire Research Note No. 941, Joint Fire Research Organization* (October 1972)

Subjects: Building fires; Fire load; Ventilation

Author's Summary

This note describes nine fires in single-storey buildings visited by the Fire Survey Group of the Fire Research Station. The construction of each building and the way this affected the fire are described. The fuels present and estimates of the burning rates they produce are given in Tables which include data from experimental fires for comparison. The study confirms previous work done on roof venting and shows that venting may restrict fire spread except where rapid burning materials are present.

M. Model Studies and Scaling Laws

Alger, R. S. (Naval Ordnance Laboratory, Silver Spring, Maryland) **and Capener, E. L.** (Stanford Research Institute, Menlo Park, California) "Aircraft Ground Fire Suppression and Rescue Systems—Basic Relationships in Military Fires. Phases I and II," *AGFSRS-72-1, AFLC-Wright-Patterson Air Force Base, Ohio* (June 1972) See **Section E.**

Miller, R. K., Jenkins, M. E., and Keller, J. A. (The Dikewood Corporation, Albuquerque, New Mexico) "Analysis of Four Models of the Nuclear-Caused Ignitions and Early Fires in Urban Areas," *DC-FR-1210 under Contract DAHC20-70-C-0222, Defense Civil Preparedness Agency* (August 1970)

Subjects: Fire ignition models; Prompt thermal ignitions; Nuclear-caused fires; Sensitivity of models; Adaptability of models

Authors' Abstract

This report details the research and analyses supporting recommendations on selection among four models of the ignition potential of nuclear attacks on urban areas. Factors investigated include accuracy of the various assumptions and analytical techniques employed by the models, sensitivity of the models to variations in input parameters, and adaptability of the models to increased knowledge of fire phenomenology. Under the criteria used, the NASL model is the best of the four. However, both improvement in data base and modification of the model would be required before its predictions would be compatible with those of existing fire spread models. Prior to these improvements, it is suggested that the IITRI model be employed, with several suggested modifications that would increase its accuracy.

Takata, A. N. (IIT Research Institute, Chicago, Illinois) "Fire Spread Model Adaptation," *Final Report, October 1972, Defense Civil Preparedness Agency Contract DAHC-20-72-C-0152.*

Subjects: Model studies; Fire prediction; Nuclear-caused fire

Author's Abstract

This study involves the continued development of computer codes to predict initiation and spread of fire in urban areas following a nuclear attack. Specifically, provisions were made in the computer codes to reflect recent improvements in the

state of knowledge in regard to firebrands, effects of blast on ignitions caused by fireball, and shielding of interior building fuels from exposure to the fireball by trees, bushes and awnings. Also allowances were made in the codes for buildings that contain room fires as well as for evaluating the consequences of removing window coverings or room items from exposure to the fireball. Detailed discussions of all the changes are included as well as an overall discussion of major features of the codes. Input/output data are described for each of the codes.

N. Instrumentation and Fire Equipment

Kelley, C. S. (Physical Research Laboratory, Edgewood Arsenal, Maryland) "Spatially Separated, Series-Linked Thermocouples," *Fire Technology* **7**(2), 101–108 (1971)

Subjects: Thermocouples (series); Series-linked thermocouples; Fire temperatures

Author's Abstract and Conclusions

Series-linked thermocouples can be used to average random heat fluctuations in flames and to reduce the amount of input data necessary to evaluate flame temperatures. Techniques that allow computation of average temperature are described and evaluated both theoretically and experimentally.

Conclusions

The use of spatially separated, series-linked thermocouples, which are symmetrically placed about a flickering flame, is shown to provide a simple yet accurate method for determining average temperatures. The method can be applied in general whenever random fluctuations occur in an otherwise symmetric heat source.

For a Chromel-Alumel thermocouple, the emf as a function of temperature over $0 \leq T \leq 1200°C$ can be closely approximated by a truncated power series. The cubic approximation (average error 3°C) is better than either a quadratic or a linear approximation (average errors 8° and 5°C, respectively).

In practice, over $40 \leq T \leq 150°C$, evaluation of an average temperature by cubic and quadratic approximations produce equal deviations (4°C) from the average temperature, whereas the deviation of the linear approximation is slightly larger (6°C). These deviations can be somewhat reduced (all to 3°C) by time averaging the response of the series-linked thermocouples.

The linear approximation, when used in a time-averaged manner, can quite accurately predict average flame temperatures. It is anticipated, however, that the cubic approximation will be more accurate over larger temperature ranges ($0 \leq T \leq 1200°C$, for example).

Lawson, D. I. (Joint Fire Research Organization, Boreham Wood, Herts., England) "A Laser Beam Fire Detection System," *Fire Technology* 6, 305 (1970) See **Section C.**

Maguire, B. A. and Barker, D. (Safety in Mines Research Establishment, Sheffield, England) "A Gravimetric Dust-Sampling Instrument (SIMPEDS): Preliminary Underground Trials, *Annals of Occupational Hygiene* **12**, 197–201 (1969)

Subject: Dust-sampling apparatus

Reprint of Safety in Mines Research Establishment Abstract, By Permission

An extremely portable, gravimetric respirable airborne dust-sampling instrument (SIMPEDS), which is built into a miner's cap-lamp and battery assembly, was described by Harris and Maguire (*Ann. Occup. Hyg.* **11**, 195). This paper describes preliminary underground trials of the instrument at one coal mine on a long-wall face. During the trials, the instrument was worn by individual miners working in various occupations on the face. Thus, in addition to demonstrating the "pitworthiness" of the instrument, it was also possible to obtain a limited amount of data about the dust exposures associated with particular face operations. The results of these limited trials suggest that the gravimetric dust exposure of a number of different face occupations is, on average, not significantly different from or is less than the gravimetric dust exposure as measured at the routine sampling point on the return roadway. For the rippers (who enlarged the mine roadways by taking out the roof), the mean dust exposure is 13% higher than the return value.

O'Sullivan, E. F., Ghosh, B. K., and Turner, J. (Joint Fire Research Organization, Boreham Wood, Herts., England) "Experiments on the Use of a Laser Beam for Heat Detection," *Fire Technology* **7**(2), 133–141 (1971) See **Section C.**

Smith, W. K. and Kelly, H. R. (Naval Weapons Center, China Lake, California) "A Passive Recording Heat Flux Indicator," *Fire Technology* 7, 5–14 (1971)

Subjects: Heat flux indicator; Passive heat flux indicator

Authors' Abstract and Conclusions

Heat flux measurements need not require complicated and time consuming electrically instrumented setups. The authors report the development of a simple, inexpensive tempered steel heat flux indicator.

Conclusions

- An inexpensive, simple device has been developed to indicate and record heat flux in large fires without the need for electrical instrumentation.
- A plain high carbon steel is well suited for the use of the tempering process as a means of measuring and recording the effects of temperature and time.
- The use of two thicknesses of steel strip specimens allows the simultaneous solution of the heat balance equation for both time and temperature; the same thicknesses of two steels with different tempering rates do not give this information.
- The service time of this device may be extended by adding high-conductivity heat sinks.
- Rockwell "C" hardness tests must be made with utmost care in techniques and calibration to achieve acceptable accuracy with this device.

O. Miscellaneous

Crees, Mrs. J. C. and Mealing, P. (Joint Fire Research Organization, Boreham Wood, Herts., England) "References to Scientific Literature on Fire, Part XXI, 1970," *Department of the Environment and Fire Offices' Committee, Joint Fire Research Organization* (1970)

Subjects: Fire research literature

Authors' Summary

The references in this part of the bibliography relate chiefly to information noted by the library during 1970. The following method of classification has been used:—

Fowler, L. C. (Joint Fire Research Organization, Boreham Wood, Herts., England) "Collected Summaries of Fire Research Notes 1971," *Fire Research Note No. 939, Joint Fire Research Organization* (July 1972)

Subjects: Fire research, review; Joint Fire Research Station Notes; Boreham Wood Fire Notes

Author's Summary

These summaries were prepared for the Fire Offices' Committee but it is thought that they may have general interest. (Covers Notes 792–887)

Whitney, A. W. (California Institute of Technology, Pasadena, California) "On Insurance Settlements Incident to the 1906 San Francisco Fire," *DRC-72-01, The Center for Research on the Prevention of Natural Disasters, Division of Engineering and Applied Science, California Institute of Technology* (1972)

Subjects: Insurance; San Francisco Fire (1906)

Author's Index

BOOKS

Building Construction for the Fire Service by Francis L. Brannigan. Published by the National Fire Protection Association, Boston, Massachusetts, 1972.

Reviewed by R. L. Tuve

This interesting and engagingly written book has been compiled by a "fireman's fireman", now turned an erudite and eloquent teacher, for and to the fireman, fire officer, and fire protection specialist. Its pages are replete with specific examples and references to the subject matter in the form of illustrations, drawings, case histories, and even admonitions to the fire fighter who finds himself confronted with the problem in building construction under discussion.

The basic principles of construction and loading are first covered in an accurate and not too complicated a manner with a discussion of forces acting upon various types of construction.

Wood construction, steel, and concrete building design are each treated thoroughly in separate chapters. The effects of fire in these types of buildings are never neglected; the examples and illustrations used are oriented toward the fire fighter's approach to fire-weakened construction. The author refers to steel as a "thermoplastic material" because of its strength-yielding characteristics in the face of heat and fire.

Ordinary construction with its mixture of brick, wood, and steel is covered in detail in a long chapter. The many artifices employed by masons and carpenters which may add up to serious pitfalls and yield difficult fire problems for the fire fighter are illustrated and pointed out in detail. Even the preplanning of a fire and its "size-up" are outlined.

The author's fondness for the exposition of the older nineteenth century so-called "fireproof" building construction is evident in a chapter devoted to this subject. Fire resistance of construction materials and their testing are also explained.

Throughout the text the author's serious efforts to debunk the entire building construction situation as it applies to the working fireman are seen. For instance, the commonly used term, "calculated risk" is dissected and shown to really mean "in case of fire—let it go."

The wealth of information contained in this little volume, as it pertains to fire protection and fire fighting, is worth detailed study by the fire officer. It could well be used during the course of study of architects and construction engineers, professions that seem to be wanting in guidance concerning fire protection matters.

Fire Retardant Formulations Handbook by Vijay M. Bhatnagar. Published by Technomic Publishing Company, Westport, Connecticut, 1972.

Publisher's Note

Here in one convenient handbook are major fire retardant formulations for the most widely used flammable materials:

- 206 for woods and paints
- 103 for plastics and other polymers
- 47 for textiles and papers
- 44 for other important materials

Included in the above are formulations for elastomers, neoprene, rug backing, caulking compound, mastic, plaster, tile, and fiberboard.

In addition to complete formulations, the original source of each formulation is indicated—author, manufacturer, laboratory, or association. These sources are also listed in an index so one can quickly locate formulations by source. A subject index also enables one to find formulations by material or product.

Hazardous Chemicals Data. Published by National Fire Protection Association, Boston, Massachusetts, 1972

Publisher's Note

Information on 19 chemicals not previously included appears in the 1972 edition of "Hazardous Chemicals Data" (NFPA No. 49), is now available from the National Fire Protection Association.

The entry for each of some 270 chemicals covered in this manual gives its description, fire and explosion hazards, life hazard, fire fighting advice, usual shipping containers, storage recommendations, and hazard rating number. Numerous cross-references add to this publication's usefulness.

Widely referred to as a guide to good practice, NFPA No. 49 is an invaluable reference work for industrial firms using chemicals and for transporters. Its information on fire and health hazards and recommendations on fire fighting make it particularly useful for the fire service as well. The current 266-page text, adopted at the 1972 NFPA Annual Meeting, has been revised editorially in addition to being updated to include newly developed information.

NFPA No. 49 is the work of the NFPA Committee on Chemicals and Explosives through its Sectional Committee on Properties of Hazardous Chemicals.

National Fire Codes, 1972–73 (10 Volumes). Published by National Fire Protection Association, Boston, Massachusetts, 1972.

Publisher's Bulletin

The 1972–73 edition of the National Fire Codes is now available from the National Fire Protection Association (NFPA). Published in ten volumes, the Codes consist of 220 authoritative fire safety standards, codes, recommended practices, and manuals. There are 8,972 pages, size 5 by 7-5/8 inches, and each volume has a sewed binding with durable plastic-coated cover.

Sixty-eight standards, or nearly one-third of the total number appearing in the new edition of the Codes, are printed in versions adopted at the 1972 NFPA Annual Meeting. Of these, four are completely new; many have undergone extensive revision and organization or contain important changes reflecting recent fire experience and technological developments.

Codes are priced at $5 per volume and $40 for the complete ten-volume set. Subjects and contents of each volume are as follows:

Volume 1, FLAMMABLE LIQUIDS, OVENS and BOILER-FURNACES (1,044 pages, 23 standards) including the Flammable and Combustible Liquids Code; oil burning equipment; classification of flammable liquids; identification system for fire hazards of materials; dry cleaning plants; cleaning small tanks; spray finishing; dip tanks; manufacture of organic coatings; portable shipping tanks; ovens and furnaces.

Volume 2, GASES (840 pages, 18 standards) including installation of gas appliances and gas piping; liquefied petroleum gas storage and handling; inhalation anesthetics and therapy; liquefied hydrogen systems; storage and handling of liquefied natural gas; hyperbaric facilities; the new standard for hypobaric facilities.

Volume 3, COMBUSTIBLE SOLIDS, DUSTS and EXPLOSIVES (954 pages, 31 standards) including Hazardous Chemicals Data; Code for Explosive Materials; Model Rocketry Code; Model State Fireworks Law; manufacture and storage of pyroxylin plastics; pneumatic conveying systems; flammability of wearing apparel; grain elevators and bulk grain handling facilities; terminals for motor vehicles carrying explosives.

Volume 4, BUILDING CONSTRUCTION and FACILITIES (844 pages, 26 standards) including the Life Safety Code; Lightning Protection Code; glossary of heating terms; fire doors and windows; incinerators; clearances for heat-producing appliances; commercial cooking equipment; roof coverings; chimneys, fireplaces and venting systems; protection of buildings from exterior fire exposure; construction and demolition operations.

Volume 5, ELECTRICAL (982 pages, 9 standards) including the current (1971) National Electrical Code; Dwelling Electrical Code; electronic computer systems; electrical systems for hospitals; electrical metalworking machine tools; intrinsically safe process control equipment; purged enclosures for electrical equipment.

Volume 6, SPRINKLERS, FIRE PUMPS and WATER TANKS (626 pages, 8 standards) including installation and maintenance of sprinkler systems; centrifugal fire pumps; water tanks; outside protection.

Volume 7, ALARM and SPECIAL EXTINGUISHING SYSTEMS (840 pages, 20 standards) including the standards for household fire warning equipment; standpipes and hose systems; central station, local, auxiliary, proprietary and remote station signaling systems; explosion prevention systems; extinguishing systems using foam, carbon dioxide, Halon 1301 and other agents; the new standard on Halon 1211 extinguishing systems.

Volume 8, PORTABLE and MANUAL FIRE CONTROL EQUIPMENT (906 pages, 29 standards) including model drafts for enabling legislation; model enabling act for sale or leasing and servicing of fire extinguishers; fire department organization and management; industrial fire loss prevention; installation and maintenance of portable fire extinguishers; automotive fire apparatus; forest fire control; coding systems for fire reporting; hospital emergency preparedness; manual for watchmen and guards.

Volume 9, OCCUPANCY STANDARDS and PROCESS HAZARDS (948 pages, 27 standards) including lumberyards; fur storage; piers and wharves; garages; mobile homes; general storage indoors and out; hospital laboratories; record protection; facilities handling radioactive materials; protection of library and museum collections, recreational vehicles; the new standard for archives and record centers.

Volume 10, TRANSPORTATION (988 pages, 29 standards) including protection of vessels during construction; aircraft rescue and fire fighting services at airports and vehicles for performing these services; aircraft fueling; aircraft fire extinguishers; hangars; welding operations in hangars; cabin cleaning operations; aircraft ramp hazard classifications; truck fire protection; the new aircraft fire investigation handbook.

In accordance with NFPA objectives, the National Fire Codes are intended to serve as reasonable measures for minimizing losses of life and property from fire. These standards are widely used in the United States, Canada and abroad as bases for government regulations at all levels and as guides to good practice.

Tentative Guide for Plastics in Building Construction. Published by National Fire Protection Association, Boston, Massachusetts, 1972

Publisher's Bulletin

An educational manual prepared in response to the rapidly growing application of a wide range of synthetic materials is the new National Fire Protection Association (NFPA) "Tentative Guide for Plastics in Building Construction" (NFPA No. 205M-T).

With emphasis on explaining the fire characteristics of plastics, not generally understood, this new 24-page text is the work of the NFPA Committee on Building Construction with the assistance of authorities in the plastics industry. Provisions of the guide apply to sheet and molded plastics and to foamed plastics such as cellular polystyrene and urethane.

In its current form, this guide was tentatively adopted at the 1972 NFPA Annual Meeting. It is subject to revision before being submitted for official NFPA adoption.

Meetings

The Fifteenth Symposium (International) on Combustion, Toshi Center Hall, Tokyo, Japan, August 25–31, 1974.

Colloquia in the following areas are planned:

Kinetics of Elementary Reactions
Fire and Explosion Research and Safety
Pollution Control in and by Combustion Systems
Combustion in Practical Systems

Information concerning the symposium may be obtained from

Japanese Section of The Combustion Institute
Department of Reaction Chemistry
Faculty of Engineering
University of Tokyo
Bunkyo-ku, Tokyo 113, Japan

Symposium on Physiological and Toxicological Aspects of Combustion Products. University of Utah, Salt Lake City, Utah, March 18–20, 1974. Sponsored by the Committee on Fire Research, National Research Council—National Academy of Sciences, Washington, D.C.

Information concerning the symposium may be obtained from

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THE COMMITTEE ON FIRE RESEARCH functions within the Division of Engineering to stimulate and advise on research directed toward the development of new knowledge and new techniques that may aid in preventing or controlling wartime and peacetime fires. The Committee was established in December of 1955 at the request of the Federal Civil Defense Administration. It is supported by the Defense Civil Preparedness Agency of the Department of the Army, the U.S. Department of Agriculture through the Forest Service, the National Science Foundation, and the National Bureau of Standards.

Volume 15 1973 Number 2

Fire Research Abstracts and Reviews

National Academy of Sciences

FIRE RESEARCH ABSTRACTS AND REVIEWS

FIRE RESEARCH ABSTRACTS AND REVIEWS will abstract papers published in scientific journals, progress reports of sponsored research, patents, and research reports from technical laboratories. At intervals, reviews on subjects of particular importance will be published. The coverage will be limited to articles of significance in fire research, centered on the quantitative understanding of fire and its spread.

Editor: Robert M. Fristrom, Applied Physics Laboratory
The Johns Hopkins University, Silver Spring, Maryland

Editorial Staff: Geraldine Fristrom, Mary D. Kalas

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Committee on Fire Research
Division of Engineering
National Research Council

NATIONAL ACADEMY OF SCIENCES
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FOREWORD

The issue begins with a bibliography on flame structure. This area of combustion science contributes to the understanding of the detailed reaction kinetics of fires.

Three symposia related to fire problems are reported: (1) the yearly meeting of the Belgian section of the Combustion Institute where fire problems were the principal topic; (2) the European symposium on Combustion in Sheffield where fire problems were a major topic; and, (3) the symposium on Smoke and Air Quality from Urban Forest Fires sponsored by the Committee on Fire Research. Finally, we welcome a new journal in the field of combustion and fires. This is a Polish journal, *Archiwn Procesow Spalania* (Archives of Combustion Processes), edited by Professor S. Wojcicki. We will follow the course of this journal with interest.

The Congress is currently reconsidering the problems of fire safety. Two bills on fire problems have been introduced into the Congress and remain to be reconciled. Hopefully, by the publication of this issue, a new improved federal policy on fire problems may be initiated with a resultant revitalization of research efforts in fighting unwanted fires.

ROBERT M. FRISTROM, *Editor*

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Bibliography on Flame Structure (1934-1972)*

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Introduction

The study of the structure of laminar flames, an active branch of combustion research, is concerned with measuring the detailed temperature and composition profiles of flames and interpreting this information to explain flame behavior and elementary flame processes. The most significant flame processes are chemical reaction, convection, diffusion, thermal conduction, and thermal diffusion.

Among the early observations of flame structure are those of Bunsen and Faraday. For many years it was felt that flame processes were too rapid and took place in such steep temperature and composition gradients that meaningful measurements could not be made. Major developments in this field occurred in the early 1950's with the formulation of a rigorous flame theory [Hirschfelder, Curtis, and Bird (1954)], which allowed reliable interpretation of flame data and the development of experimental techniques suitable for direct measurement of local concentrations, temperatures, and velocities in flame fronts with sufficient precision to allow meaningful gradients to be determined.

Three books have appeared on the subject: C. P. Fenimore's *Chemistry of Premixed Flames;* F. J. Weinberg's *Optics of Flames,* an excellent brief survey which covers optical techniques and flames; and R. M. Fristrom and A. A. Westenberg's *Flame Structure,* which contains a detailed discussion of the theory and experimental methods used in quantitative interpretation of flame structure, together with a review of the field to 1965. The present bibliography updates these studies to the beginning of 1972. Papers from the *Thirteenth Symposium (International) on Combustion* as well as scattered later references are included.

The past decade has seen a number of significant advances in research on flame structure. Among these are techniques for the quantitative determination of the concentrations of atoms and radicals. Several methods have been developed: 1) Scavenger techniques [Fristrom (1963d)], in which radicals are sampled by quartz microprobes and reacted with a scavenger to produce a characteristic product molecule whose concentration is related quantitatively to the original radical species. 2) Spectroscopic absorption, emission, and gas–phase titration techniques, in which the radical concentration is inferred from the emission of tracer species [Bonne (1969)]. 3) ESR sampling [Westenberg and Fristrom (1969)], in which radical species are collected by a microprobe and rapidly transferred into an ESR cavity for analysis. 4) Molecular beam sampling [Foner (1954)], in which radicals are sampled by a molecular beam inlet mass spectrometer and radicals are identified by their low ionization potential.

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The introduction of the laser has ushered in many new and exciting possibilities for flame studies both in the direct study of flame optics [Weinberg (1963)] and in the study of the composition and temperature of flame species. The maturation of direct molecular beam mass spectrometry, which permits study of an approximately collisionless sample, stems from the pioneer work of Foner and Hudson [Foner (1954)] as a relatively routine instrument, but a number of problems remain [Fristrom (1972)]. Improvement in laboratory instruments, coupled with software innovations in data manipulation, hold promise for large-scale, high-precision studies of flame systems. Computer interpretation of complete flames in terms of elementary reaction processes have been made by Dixon-Lewis (1967b) and Hoyerman (1971). The agreement between kinetic information derived from flames and the results of elementary studies have removed much of the aura of witchcraft from flame studies. Spectroscopic studies of excited species in flames [Gaydon (1957)] have great potential for unraveling combustion mechanisms. At low pressure, flame emission probability increases relative to collision deactivation (because the mean time between collisions varies with the mean free path; i.e., p^{-1}). New research tools and techniques present many intriguing prospects for the coming years.

In this bibliography, articles are presented alphabetically by primary author in chronological order. Author cross references and a subject index have been prepared using the INFO-360 document-writing package of the Applied Physics Laboratory, the Johns Hopkins University. Since this bibliography was composed by computer, certain notational conventions had to be modified. For example, chemical subscripts are printed on the same line in parentheses: e.g., 0(2) for molecular oxygen.

Titles of journal articles are printed in capitals; journal and symposium titles are in upper and lower case in italics; book titles are in upper and lower case boldface.

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Bibliography

—A—

Agnew (1965)
Agnew, W. G. and Agnew, J. T.
COMPOSITION PROFILES OF THE DIETHYL ETHER-AIR TWO-STAGE REACTION STABILIZED IN A FLAT-FLAME BURNER
Tenth Symposium (International) on Combustion, The Combustion Institute, 123 (1965)

Aldred (1969)
Aldred, J. W. and Williams, A.
THE FLAME STRUCTURE OF BURNING SPHERES OF LIQUID METHANOL
Combustion and Flame, **13,** 559 (1969)

Ambs (1971)
Ambs, L. W. and Fletcher, E. A.
CHLORINE-FLUORINE FLAME STRUCTURE
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 685 (1971)

Anderson (1949)
Anderson, J. W. and Fein, R. S.
NORMAL BURNING VELOCITIES AND BUNSEN FLAME TEMPERATURES FROM STROBOSCOPICALLY ILLUMINATED PARTICLE TRACKS
J. Chem. Phys., **17,** 1268 (1949)

Andrew (1948)
Andrew, E. R., Axford, D. W. E., and Sugden, T. M.
THE MEASUREMENT OF IONIZATION IN A TRANSIENT FLAME
Trans. Faraday Soc., **44,** 427 (1948)

Arden (1958)
Arden, E. A. and Powling, J.
THE METHYL NITRATE DECOMPOSITION FLAME
Combustion and Flame, **2,** 55 (1958)

Azatyan (1969)
Azatyan, V. V., Gershenson, U. M., Sarkissyan, E. N., Sachyan, G. A. and Nalbandyan, A. B.
INVESTIGATION OF LOW-PRESSURE FLAMES OF A NUMBER OF COMPOUNDS CONTAINING SULFUR BY THE ESR METHOD
Twelfth Symposium (International) on Combustion, The Combustion Institute, 989 (1969)

—B—

Ballinger (1971)
Ballinger, P. R. and Ryason, P. R.
ISOLATED STABLE COOL FLAMES OF HYDROCARBONS
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 271 (1971)

Barnard (1962)
Barnard, J. A. and Cullis, C. F.
THE RATES OF CHEMICAL REACTION IN THE DIETHYLENE DIFFUSION FLAME
Eighth Symposium (International) on Combustion, The Combustion Institute, 481 (1962)

Bascombe (1962)
Bascombe, K. N., Green, J. A. and Sugden, T. M.
THE IONIZATION PRODUCED BY ADDITION OF ACETYLENE TO A HYDROGEN-OXYGEN-NITROGEN FLAME
Advances in Mass Spectrometry, **2,** Pergamon Press, New York, 66 (1962)

Bascombe (1965)
Bascombe, K. N.
HYDROGEN-ATOM CONCENTRATIONS IN HYDROGEN-OXYGEN-NITROGEN FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 55 (1965)

Belcher (1950)
Belcher, H. and Sugden, T. M.
STUDIES ON THE IONIZATION PRODUCED BY METALLIC SALTS IN FLAMES: I. THE DETERMINATION OF THE COLLISION FREQUENCY OF ELECTRONS IN COAL-GAS + AIR FLAMES
Proc. Roy. Soc., **A202,** 17 (1950)

Bell (1971)
Bell, J. C., Bradley, D. and Jesch, L. F.
CHEMI-IONIZATION, CHEMILUMINESCENCE, AND ELECTRON ENERGY EXCHANGE IN HYDROCARBON-AIR FLAMES
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 311 (1971)

Biedler (1957)
Biedler, W. T. and Hoelscher, H. E.
STUDIES IN A NEW TYPE OF FLAT FLAME BURNER
Jet Propulsion, **27,** 1257 (1957)

Bonne (1960)
Bonne, U., Grewer, Th. and Wagner, H. Gg.
MESSUNGEN IN DER REAKTIONSZONE VON WASSERSTOFFE-SAUERSTOFF UND METHAN-SAUERSTOFF FLAMMEN [Measurements in the Reaction Zone of H(2)—O(2) and CH(2)—O(2) Flames]
Z. Physik. Chem., Frankfurt, Neue Folge, **26,** 93 (1960)

Bonne (1965a)
Bonne, U. and Wagner, H. Gg.
UNTERSUCHUNG DES REAKTIONSABLAUFS IN FETTEN KOHLENWASSERSTOFFE-SAUERSTOFF-FLAMMEN III. OPTICHE UNTERSUCHUNGEN AN RUSSENDED FLAMMEN [Research on the Problems of Reaction in Rich Hydrocarbon-Oxygen Flames; III. Optical Research on Smoky Flames]
Ber. Bunsenges. Phys. Chem., **69,** 35 (1965)

Bonne (1965b)
Bonne, U., Homann, K. H., and Wagner, H. Gg.
CARBON FORMATION IN PREMIXED FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 503, (1965)

Boothman (1969)
Boothman, D., Lawton, J., Melinek, S. J. and Weinberg, E. J.
RATES OF ION GENERATION IN FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 969 (1969)

Bradley (1965)
Bradley, J. N., Jones, G. A., Skirrow, G. and Tipper, C. E. H.
A MASS-SPECTROMETRIC STUDY OF STABILIZED LOW-TEMPERATURE FLAMES OF ALDEHYDES
Tenth Symposium (International) on Combustion, The Combustion Institute, 139 (1965)

Bradley (1967)
Bradley, D. and Matthews, K. J.
IONIZATION AND ELECTRON TEMPERATURES IN CARBON MONOXIDE AND HYDROGEN FLAMES WITH ADDED METHANE
Eleventh Symposium (International) on Combustion, The Combustion Institute, 359 (1967)

Bradley (1969)
Bradley, J. N., Gilbert, J. R., and Jones, G. A.
PROPYLENE OXIDE-OXYGEN FLAMES
Combustion and Flame, **13,** 668 (1969)

Breisacher (1959)
Breisacher, P., Dembrow, D., and Berl, W. G.
FLAME FRONT STRUCTURES OF LEAN DIBORANE-AIR AND DIBORANE-HYDROCARBON-AIR MIXTURES
Seventh Symposium (International) on Combustion, The Combustion Institute, 894 (1959)

Browne (1969)
Browne, W. G., Porter, R. P., Verlin, J. D., and Clark, A. H.
A STUDY OF ACETYLENE-OXYGEN FLAMES
Twelfth Symposium (International) on Combustion, The Combustion Institute, 1035 (1969)

Bulewicz (1954)
Bulewicz, E. M., James, C. G., and Sugden, T. M.
PHOTOMETRIC INVESTIGATIONS OF ALKALI METALS IN HYDROGEN FLAME GASES: I. A GENERAL SURVEY OF THE USE OF RESONANCE RADIATION IN THE MEASUREMENT OF ATOMIC CONCENTRATIONS
Proc. Roy. Soc., **A227,** 312 (1954)

Bulewicz (1956a)
Bulewicz, E. M., James, C. G., and Sugden, T. M.
PHOTOMETRIC INVESTIGATION OF ALKALI METALS IN HYDROGEN FLAME GASES: II. THE STUDY OF EXCESS CONCENTRATIONS OF HYDROGEN ATOMS IN BURNT GAS MIXTURES
Proc. Roy. Soc., **A235,** 89 (1956)

Bulewicz (1956b)
Bulewicz, E. M. and Sugden, T. M.
DETERMINATION OF THE DISSOCIATION CONSTANTS AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY. Part II. HEAT OF FORMATION OF GASEOUS CUPROUS HYDROXIDE
Trans. Faraday Soc., **52,** 1475 (1956)

Bulewicz (1956c)
Bulewicz, E. M. and Sugden, T. M.
DETERMINATION OF THE DISSOCIATION CONSTANTS AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY. Part III. STABILITY OF GASEOUS CUPROUS HYDROXIDE
Trans. Faraday Soc., **52,** 1481 (1956)

Bulewicz (1958a)
Bulewicz, E. M. and Sugden, T. M.
DETERMINATION OF THE DISSOCIATION CONSTANTS AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY. Part IV. The STABILITY OF GaOH, InOH, and T1H
Trans. Faraday Soc., **54,** 830 (1958)

Bulewicz (1958b)
Bulewicz, E. M. and Sugden, T. M.
THE RECOMBINATION OF HYDROGEN ATOMS AND HYDROXYL RADICALS IN HYDROGEN FLAME GASES
Trans. Faraday Soc., **54,** 1855 (1958)

Bulewicz (1958c)
Bulewicz, E. M. and Sugden, T. M.
STUDIES OF OXYGEN ATOMS AT HIGH TEMPERATURES
Special Publication No. 9, Chemical Society (London), 81 (1958)

Bulewicz (1959)
Bulewicz, E. M. and Sugden, T. M.
DETERMINATION OF THE DISSOCIATION CONSTANTS AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY. Part V. THE STABILITY OF MgO and MgOH
Trans. Faraday Soc., **55,** 720 (1959)

Bulewicz (1967)
Bulewicz, E. M.
SOME OBSERVATIONS ON CHEMILUMINESCENCE AND CHEMI-IONIZATION IN FLAMES
Combustion and Flame, **11,** 297 (1967)

Bulewicz (1969)
Bulewicz, E. M.
A PHOTOMETRIC STUDY OF THE EMISSION SPECTRA OF CYANOGEN FLAMES AT REDUCED PRESSURE
Twelfth Symposium (International) on Combustion, The Combustion Institute, 957 (1969)

Bulewicz (1970)
Bulewicz, E. M., Padley, P. J., and Smith, R. E.
SPECTROSCOPIC STUDIES OF O(2), CH, AND OH RADICALS IN LOW PRESSURE ACETYLENE + OXYGEN FLAMES
Proc. Roy. Soc., **A315,** 129 (1970)

Burge (1969)
Burge, S. J. and Tipper, C. F. H.
THE BURNING OF POLYMERS
Combustion and Flame, **13,** 495 (1969)

Burgoyne (1953)
Burgoyne, J. H. and Weinberg, F. J.
A METHOD OF ANALYSIS OF A PLANE COMBUSTION WAVE
Fourth Symposium (International) on Combustion, The Combustion Institute, 294 (1953)

Burgoyne (1954)
Burgoyne, J. H. and Weinberg, F. J.

DETERMINATION OF THE DISTRIBUTION OF SOME PARAMETERS ACROSS THE COMBUSTION ZONE IN A FLAME FRONT
Trans. Faraday Soc., **47,** 1106 (1951)

Burgoyne (1957)
Burgoyne, J. H. and Weinberg, F. J.
STUDIES OF THE MECHANISM OF FLAME PROPAGATION IN PREMIXED GASES
Z. für Elektrochem., Bunsengesellschaft Symposium, **61,** 565 (1957)

—C—

Calcote (1949)
Calcote, H. F.
ELECTRICAL PROPERTIES OF FLAMES—BURNER FLAMES IN TRANSVERSE ELECTRIC FIELDS
Third Symposium on Combustion, Flame, and Explosion Phenomena, Williams and Wilkins Co., Baltimore, 245 (1949)

Calcote (1951)
Calcote, H. F. and Pease, R. N.
ELECTRICAL PROPERTIES OF FLAMES—BURNER FLAMES IN LONGITUDINAL ELECTRICAL FIELDS
Ind. Eng. Chem. **43,** 2726 (1951)

Calcote (1955)
Calcote, H. F. and King, I. R.
STUDIES OF IONIZATION IN FLAMES BY MEANS OF LANGMUIR PROBES
Fifth Symposium (International) on Combustion, The Combustion Institute, 423 (1955)

Calcote (1957)
Calcote, H. F.
MECHANISM FOR THE FORMATION OF IONS IN FLAMES
Combustion and Flame, **1,** 385 (1957)

Calcote (1959)
Calcote, H. F.
RELAXATION PROCESSES IN PLASMA
Dynamics of Conducting Gases. Proceedings of the Third Biennial Gas Dynamics Symposium, August 1959, Northwestern University Press, Evanston, Illinois, 36 (1960)

Calcote (1962a)
Calcote, H. F.
NONEQUILIBRIUM IONIZATION IN FLAMES
ARS Ions in Flames and Rocket Exhausts Conference, October 11-12, 1962, Palm Springs, California. ARS Preprint 2583-62.
See: *AAIA Progress in Astronautics and Aeronautics*, **12:** "Ions and Electrons in Combustion Systems."

Calcote (1962b)
Calcote, H. F.
ION PRODUCTION AND RECOMBINATION IN FLAMES
Eighth Symposium (International) on Combustion, The Combustion Institute, 184 (1962)

Calcote (1962c)
Calcote, H. F.
NONEQUILIBRIUM IONIZATION OF FLAMES
Prog. Astronaut. Aeron., **12,** 107-144 (1962)

Calcote (1963a)
Calcote, H. F. and Reuter, J. L.
MASS-SPECTROMETRIC STUDY OF ION PROFILES IN LOW-PRESSURE FLAMES
J. Chem. Phys., **38,** 310 (1963)

Calcote (1963b)
Calcote, H. F.
ION AND ELECTRON PROFILES IN FLAMES
Ninth Symposium (International) on Combustion, The Combustion Institute, 622 (1963)

Calcote (1965)
Calcote, H. F., Kurzius, S. C., and Miller, W. J.
NEGATIVE AND SECONDARY ION FORMATION IN LOW-PRESSURE FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 605 (1965)

Calcote (1966)
Calcote, H. F. and Jensen, D. E.
ION-MOLECULE REACTIONS IN FLAMES
Advan. Chem. Ser., No. 58, 291 (1966)

Carabetta (1967)
Carabetta, R. and Kaskan, W.
CHEMI-EXCITATION OF SODIUM IN FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 321 (1967)

Carabetta (1969)
Carabetta, R. and Porter, R. P.
ABSOLUTE POSITIVE-ION CONCENTRATION MEASUREMENTS IN FLAMES WITH LANGMUIR PROBES
Twelfth Symposium (International) on Combustion, The Combustion Institute, 423 (1969)

Chase (1963)
Chase, J. D. and Weinberg, F. J.
THE ACETYLENE DECOMPOSITION FLAME AND THE DEDUCTION OF REACTION MECHANISM FROM 'GLOBAL' FLAME KINETICS
Proc. Roy. Soc., **A275,** 411 (1963)

Child (1959)
Child, E. T. and Wohl, K.
SPECTROPHOTOMETRIC STUDIES OF LAMINAR FLAMES: I. THE DECAY OF RADICAL RADIATION
Seventh Symposium (International) on Combustion, The Combustion Institute, 215 (1959)

Clarke (1968)
Clarke, J. F.
ON THE STRUCTURE OF A HYDROGEN-OXYGEN DIFFUSION FLAME
Proc. Roy. Soc., **A307,** 283 (1968)

Cole (1957a)
Cole, D. J. and Minkoff, G. J.
EXPERIMENTAL TECHNIQUES FOR THE STUDY OF FLAT FLAMES BY INFRARED SPECTROSCOPY
Combustion and Flame, **1,** 241 (1957)

Cole (1957b)
Cole, D. J. and Minkoff, G. J.

CARBON FORMATION IN DIFFUSION FLAMES AND THE ROLE OF ACETYLENE
Proc. Roy. Soc., **A239,** 280 (1957)
Cotton (1970)
Cotton, D. M.
THE STRUCTURE OF FLAMES
Science Progress, **58,** 161 (1970)
Cummings (1967)
Cummings, G.A.McD. and Hutton, E.
IONIZATION IN ETHYLENE-AIR-NITRIC OXIDE FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, (1967)

—D—

Day (1971)
Day, M. J., Stamp, D. V., Thompson, K., and Dixon-Lewis, G.
INHIBITION OF HYDROGEN-AIR AND HYDROGEN-NITROUS OXIDE FLAMES BY HALOGEN COMPOUNDS
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 705 (1971)
Deckers (1959)
Deckers, J. and Van Tiggelen, P.
ION-IDENTIFICATION IN FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 254 (1959)
Dixon-Lewis (1951)
Dixon-Lewis, G. and Wilson, J. G.
A METHOD FOR THE MEASUREMENT OF THE TEMPERATURE DISTRIBUTION IN THE INNER CORE OF A BUNSEN FLAME
Trans. Faraday Soc., **47,** 1106 (1951)
Dixon-Lewis (1953)
Dixon-Lewis, G.
TEMPERATURE DISTRIBUTION IN FLAME REACTION ZONES
Fourth Symposium (International) on Combustion, The Combustion Institute, 263 (1953)
Dixon-Lewis (1961)
Dixon-Lewis, G. and Williams, A.
METHODS FOR INVESTIGATING FREE-RADICAL REACTIONS IN A HYDROGEN-OXYGEN FLAME IN THE REGION OF 1000°K
Fifth International Symposium on Free Radicals, Uppsala, 1 (1961)
Dixon-Lewis (1962a)
Dixon-Lewis, G., Sutton, M. M., and Williams, A.
THE KINETICS OF HYDROGEN ATOM RECOMBINATION
Disc. Faraday Soc., **33,** 205 (1952)
Dixon-Lewis (1962b)
Dixon-Lewis, G. and Isles, G. L.
FLAME STRUCTURE STUDIES
Eighth Symposium (International) on Combustion, The Combustion Institute, 448 (1962)
Dixon-Lewis (1962c)
Dixon-Lewis, G. and Isles, G. L.
SHARP-FOCUSING SCHLIEREN SYSTEMS FOR STUDIES OF FLAT FLAMES
J. Sci. Instrum., **39,** 148 (1962)

Dixon-Lewis (1962d)
Dixon-Lewis, G. and Williams, A.
ROLE OF HYDROPEROXYL IN HYDROGEN-OXYGEN FLAMES
Nature, **196,** 1309 (1962)

Dixon-Lewis (1963a)
Dixon-Lewis, G. and Williams, A.
SOME OBSERVATIONS ON THE STRUCTURE OF A SLOW BURNING FLAME SUPPORTED BY THE REACTION BETWEEN HYDROGEN AND OXYGEN AT ATMOSPHERIC PRESSURE
Ninth Symposium (International) on Combustion, The Combustion Institute, 576 (1963)

Dixon-Lewis (1963b)
Dixon-Lewis, G. and Williams, A.
METHODS OF STUDYING CHEMICAL KINETICS IN FLAMES
Quart. Rev., **17,** 243 (1963)

Dixon-Lewis (1964)
Dixon-Lewis, G. and Williams, A.
THE RATE OF HEAT RELEASE IN SOME SLOW BURNING HYDROGEN-OXYGEN FLAMES
Combustion and Flame, **8,** 249 (1964)

Dixon-Lewis (1965a)
Dixon-Lewis, G., Sutton, M. M., and Williams, A.
THE CHEMICAL REACTION OF HYDROGEN WITH NITROUS OXIDE
J. Chem. Soc., 5724 (1965)

Dixon-Lewis (1965b)
Dixon-Lewis, G., Sutton, M. M., and Williams, A.
SOME REACTIONS OF HYDROGEN ATOMS AND SIMPLE RADICALS AT HIGH TEMPERATURES
Tenth Symposium (International) on Combustion, The Combustion Institute, 495 (1965)

Dixon-Lewis (1965c)
Dixon-Lewis, G., Sutton, M. M., and Williams, A.
REACTIONS CONTRIBUTING TO THE ESTABLISHMENT OF THE WATER GAS EQUILIBRIUM WHEN CARBON DIOXIDE IS ADDED TO A HYDROGEN-OXYGEN FLAME
Trans. Faraday Soc., **61,** 255 (1965)

Dixon-Lewis (1967a)
Dixon-Lewis, G. and Williams, A.
SOME OBSERVATIONS ON THE COMBUSTION OF METHANE IN PREMIXED FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 951 (1967)

Dixon-Lewis (1967b)
Dixon-Lewis, G.
FLAME STRUCTURE AND FLAME REACTION KINETICS: I. SOLUTION OF CONSERVATION EQUATIONS AND APPLICATION TO RICH HYDROGEN-OXYGEN FLAMES
Proc. Roy. Soc., **A298,** 495 (1967)

Dixon-Lewis (1968)
Dixon-Lewis, G.
FLAME STRUCTURE AND FLAME REACTION KINETICS: II. TRANSPORT PROPERTIES IN MULTI-COMPONENT SYSTEMS
Proc. Roy. Soc., **A307,** 111–135 (1968)

Dixon-Lewis (1969)
Dixon-Lewis, G. and Isles, G. L.

FLAME STRUCTURE AND FLAME REACTION KINETICS: III. MEASUREMENT OF TEMPERATURE PROFILES IN FLAMES AT ATMOSPHERIC PRESSURE
Proc. Roy. Soc., **A308,** 517–536 (1969)
Dixon-Lewis (1970a)
Dixon-Lewis, G., Sutton, M. M., and Williams, A.
FLAME STRUCTURE AND FLAME REACTION KINETICS: IV. EXPERIMENTAL INVESTIGATIONS OF A FUEL-RICH HYDROGEN + OXYGEN + NITROGEN FLAME AT ATMOSPHERIC PRESSURE
Proc. Roy. Soc., **A317,** 227–234 (1970)
Dixon-Lewis (1970b)
Dixon-Lewis, G.
FLAME STRUCTURE AND FLAME REACTION KINETICS: V. INVESTIGATIONS OF REACTION MECHANISMS IN A RICH HYDROGEN + NITROGEN + OXYGEN FLAME BY SOLUTION OF CONSERVATION EQUATIONS
Proc. Roy. Soc., **A317,** 235 (1970)

—E—

Egerton (1963)
Egerton, A., Gugan, K., and Weinberg, F. J.
THE MECHANISM OF SMOULDERING CIGARETTES
Combustion and Flame, **7,** 63 (1963)
Ellis (1934)
Ellis, O. C. de C. and Morgan, E.
THE TEMPERATURE GRADIENT IN FLAMES
Trans. Faraday Soc., 287 (1934)

—F—

Fenimore (1957a)
Fenimore, C. P. and Jones, G. W.
THE WATER-CATALYZED OXIDATION OF CARBON MONOXIDE BY OXYGEN AT HIGH TEMPERATURES
J. Phys. Chem., **61,** 651 (1957)
Fenimore (1957b)
Fenimore, C. P. and Jones, G. W.
NITRIC OXIDE DECOMPOSITION AT 2200-2400°K
J. Chem. Phys., **61,** 654 (1957)
Fenimore (1957c)
Fenimore, C. P., Jones, G. W., and Moore, G. E.
CARBON FORMATION IN QUENCHED FLAT FLAMES AT 1600°K
Sixth Symposium (International) on Combustion, The Combustion Institute, 236 (1957)
Fenimore (1958a)
Fenimore, C. P. and Jones, G. W.
DETERMINATION OF OXYGEN ATOMS IN LEAN, FLAT, PREMIXED FLAMES BY REACTION WITH NITROUS OXIDE
J. Phys. Chem., **62,** 178 (1958)
Fenimore (1958b)
Fenimore, C. P. and Jones, G. W.
DETERMINATION OF HYDROGEN ATOMS IN RICH FLAT PREMIXED FLAMES BY REACTION WITH HEAVY WATER
J. Phys. Chem., **62,** 693 (1958)

Fenimore (1958c)
Fenimore, C. P. and Jones, G. W.
THE REACTION OF HYDROGEN ATOMS WITH CARBON DIOXIDE AT 1200–1350°K
J. Phys. Chem., **62,** 1578 (1958)

Fenimore (1959a)
Fenimore, C. P. and Jones, G. W.
RATE OF REACTION IN HYDROGEN, NITROUS OXIDE, AND IN SOME OTHER FLAMES
J. Phys. Chem., **63,** 1154 (1959)

Fenimore (1959b)
Fenimore, C. P. and Jones, G. W.
THE DISAPPEARANCE OF OXYGEN IN FLAMES PRINCIPALLY BY REACTION WITH HYDROGEN ATOMS
J. Phys. Chem., **63,** 1834 (1959)

Fenimore (1961a)
Fenimore, C. P. and Jones, G. W.
OXIDATION OF AMMONIA IN FLAMES
J. Phys. Chem., **65,** 298 (1961)

Fenimore (1961b)
Fenimore, C. P. and Jones, G. W.
FORMATION OF CARBON MONOXIDE IN METHANE FLAMES BY REACTION OF OXYGEN ATOMS WITH METHYL RADICALS
J. Phys. Chem., **65,** 1532 (1961)

Fenimore (1962)
Fenimore, C. P. and Jones, G. W.
RATE OF REACTION OF O + N(2)O → 2NO
Eighth Symposium (International) on Combustion, The Combustion Institute, 127 (1962)

Fenimore (1963a)
Fenimore, C. P. and Jones, G. W.
FLAME INHIBITION BY METHYL BROMIDE
Combustion and Flame, **7,** 323 (1963)

Fenimore (1963b)
Fenimore, C. P. and Jones, G. W.
DESTRUCTION OF ACETYLENE IN FLAMES WITH OXYGEN
J. Chem. Phys., **39,** 1514 (1963)

Fenimore (1963c)
Fenimore, C. P. and Jones, G. W.
THE DECOMPOSITION OF ETHYLENE AND ETHANE IN PREMIXED HYDROCARBON-OXYGEN-HYDROGEN FLAMES
Ninth Symposium (International) on Combustion, The Combustion Institute, 597 (1963)

Fenimore (1964a)
Fenimore, C. P. and Jones, G. W.
DECOMPOSITION OF SULPHUR HEXAFLUORIDE IN FLAMES BY REACTION WITH HYDROGEN ATOMS
Combustion and Flame, **8,** 281 (1964)

Fenimore (1964b)
Fenimore, C. P. and Jones, G. W.
RATE OF DESTRUCTION OF ACETYLENE IN FLAME GASES
J. Chem. Phys., **41,** 1887 (1964)

Fenimore (1964c)
Fenimore, C. P.

DESTRUCTION OF ACETYLENE IN FLAMES WITH OXYGEN
J. Chem. Phys., **40,** 2411 (1964)

Fenimore (1964d)
Fenimore, C. P.
The Chemistry of Premixed Flames, 1964, Pergamon, NY

Fenimore (1965a)
Fenimore, C. P. and Jones, G. W.
SULFUR IN BURNT GAS OF HYDROGEN-OXYGEN FLAMES
J. Phys. Chem., **69,** 3593 (1965)

Fenimore (1965b)
Fenimore, C. P. and Jones, G. W.
RADICAL RECOMBINATION AND HEAT EVOLUTION IN H(2)-O(2) FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 480 (1965)

Fenimore (1966)
Fenimore, C. P. and Jones, G. W.
MODES OF INHIBITING POLYMER FLAMMABILITY
Combustion and Flame, **10,** 295 (1966)

Fenimore (1968)
Fenimore, C. P. and Jones, G. W.
COMPARATIVE YIELDS OF SOOT FROM PREMIXED HYDROCARBON FLAMES
Combustion and Flame, **12,** 196 (1968)

Fenimore (1969)
Fenimore, C. P. and Jones, G. W.
COAGULATION OF SOOT TO SMOKE IN HYDROCARBON FLAMES
Combustion and Flame, **13,** 303 (1969)

Feugier (1965)
Feugier, A. and Van Tiggelen, A.
IDENTIFICATION OF NEGATIVE FLAME-IONS
Tenth Symposium (International) on Combustion, The Combustion Institute, 621 (1965)

Fisher (1968)
Fisher, G. D. and Hoelscher, H. E.
A STUDY OF THE AERODYNAMIC PROPERTIES OF A LIFTED FLAT FLAME
Combustion and Flame, **12,** 333 (1968)

Foner (1945)
Foner, S. and Hudson, R.
THE DETECTION OF ATOMS AND RADICALS IN FLAMES BY MASS SPECTROMETRIC TECHNIQUES
J. Chem. Phys., **21,** 1374 (1954)

Fox (1960)
Fox, M. D. and Weinberg, F. J.
OPTICAL METHODS FOR THE STUDY OF FLAMES IN TURBULENT PREMIXED GAS STREAMS
Brit. J. Appl. Phys., **11,** 269 (1960)

Fox (1962)
Fox, M. D. and Weinberg, F. J.
AN EXPERIMENTAL STUDY OF BURNER-STABILIZED TURBULENT FLAMES IN PREMIXED REACTANTS
Proc. Roy. Soc., **A268,** 222 (1962)

Friedman (1953)
Friedman, R.
MEASUREMENT OF THE TEMPERATURE PROFILE IN A LAMINAR FLAME
Fourth Symposium (International) on Combustion, The Combustion Institute, 259 (1953)
Friedman (1954)
Friedman, R. and Burke, E.
MEASUREMENT OF TEMPERATURE DISTRIBUTION IN A LOW PRESSURE FLAT FLAME
J. Chem. Phys., **22,** 824 (1954)
Friedman (1955a)
Friedman, R. and Burke, E.
A STUDY OF THE ETHYLENE OXIDE DECOMPOSITION FLAME
Fifth Symposium (International) on Combustion, The Combustion Institute, 596 (1955)
Friedman (1955b)
Friedman, R. and Cyphers, J.
FLAME STRUCTURE STUDIES: III. GAS SAMPLING IN A LOW-PRESSURE PROPANE-AIR FLAME
J. Chem. Phys., **23,** 1875 (1955)
Friedman (1956)
Friedman, R.
ANALYSIS OF FLAME-TRAVERSE STUDIES WITH GAS-SAMPLING PROBES
J. Chem. Phys., **24,** 1268 (1956)
Friedman (1959)
Friedman, R. and Nugent, R.
FLAME STRUCTURE STUDIES: IV. PREMIXED CARBON MONOXIDE COMBUSTION
Seventh Symposium (International) on Combustion, The Combustion Institute, 142 (1959)
Fristrom (1953)
Fristrom, R. M., Prescott, R., Neumann, R. K. and Avery, W. H.
TEMPERATURE PROFILES IN PROPANE-AIR FLAME FRONTS
Fourth Symposium (International) on Combustion, The Combustion Institute, 267 (1953)
Fristrom (1954)
Fristrom, R. M., Avery, W. H., Prescott, R., and Mattuck, A. J.
FLAME ZONE STUDIES BY THE PARTICLE TRACK TECHNIQUE: I. APPARATUS AND TECHNIQUES
J. Chem. Phys., 22, 106 (1954)
Fristrom (1955)
Fristrom, R. M.
NOTE ON THE VALIDITY OF ONE-DIMENSIONAL FLAME FRONT MODELS
J. Chem. Phys., **23,** 1360 (1955)
Fristrom (1956)
Fristrom, R. M.
FLAME ZONE STUDIES: II. APPLICABILITY OF ONE-DIMENSIONAL MODELS TO THREE-DIMENSIONAL LAMINAR BUNSEN FLAME FRONTS
J. Chem. Phys., **24,** 888 (1956)
Fristrom (1957a)
Fristrom, R. M., Prescott, R., and Grunfelder, C.

FLAME ZONE STUDIES: III. TECHNIQUES FOR THE DETERMINATION OF COMPOSITION PROFILES OF FLAME FRONTS
Combustion and Flame, **1,** 102 (1957)

Fristrom (1957b)
Fristrom, R. M., and Westenberg, A. A.
FLAME ZONE STUDIES: IV. MICROSTRUCTURE AND MATERIAL TRANSPORT IN A LAMINAR PROPANE-AIR FLAME FRONT
Combustion and Flame, **1,** 217 (1957)

Fristrom (1957c)
Fristrom, R. M.
STRUCTURE OF LAMINAR FLAMES
Sixth Symposium (International) on Combustion, The Combustion Institute, 96 (1957)

Fristrom (1958a)
Fristrom, R. M., Westenberg, A. A., and Avery, W. H.
ETUDE MECANISME DE LA REACTION PROPANE-AIR PAR L'ANALYSE DE PROFILS DE FRONTS DE FLAMME [Study of the Propane-Air Reaction Mechanism by Analysis of Flame Front Profiles]
Rev. Inst. France Petrole, **13,** 544 (1958)

Fristrom (1958b)
Fristrom, R. M., Avery, W. H., and Grunfelder, C.
REACTIONS OF SIMPLE HYDROCARBONS IN FLAME FRONTS—MICROSTRUCTURE OF C(2) HYDROCARBON-OXYGEN FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 304 (1958)

Fristrom (1960)
Fristrom, R. M., Grunfelder, C., and Favin, S.
METHANE-OXYGEN FLAME STRUCTURE: I. CHARACTERISTIC PROFILES IN A LOW PRESSURE, LAMINAR, LEAN, PREMIXED METHANE—OXYGEN FLAME
J. Phys. Chem., **64,** 1386 (1960)

Fristrom (1961a)
Fristrom, R. M.
EXPERIMENTAL DETERMINATION OF LOCAL CONCENTRATIONS IN FLAMES
In *Experimental Methods in Combustion Research,* J. Surugue (ed), Pergamon Press, New York (1961)

Fristrom (1961b)
Fristrom, R. M., Grunfelder, C., and Favin, S.
METHANE-OXYGEN FLAME STRUCTURE: III. CHARACTERISTIC PROFILES AND MATTER AND ENERGY CONSERVATION IN A ONE-TWENTIETH ATMOSPHERE FLAME
J. Phys. Chem., **65,** 591 (1961)

Fristrom (1962a)
Fristrom, R. M. and Westenberg, A. A.
FUNDAMENTAL PROCESSES AND LAMINAR FLAME STRUCTURE
APL Tech. Digest, **1,** 10 (1962)

Fristrom (1962b)
Fristrom, R. M. and Westenberg, A. A.
EXPERIMENTAL CHEMICAL KINETICS FROM METHANE—OXYGEN LAMINAR FLAME STRUCTURE
Eighth Symposium (International) on Combustion, The Combustion Institute, 438 (1962)

Fristrom (1963a)
Fristrom, R. M.

THE CHEMISTRY OF COMBUSTION IN FLAMES
Chem. Eng. News, **41,** 150 (1963)
Fristrom (1963b)
Fristrom, R. M.
EXPERIMENTAL METHODS FOR STUDYING FLAME STRUCTURE
APL/JHU BB-330, (1963)
Fristrom (1963c)
Fristrom, R. M.
RADICAL CONCENTRATIONS AND REACTIONS IN A METHANE—OXYGEN FLAME
Ninth Symposium (International) on Combustion, The Combustion Institute, 560 (1963)
Fristrom (1963d)
Fristrom, R. M.
SCAVENGER PROBE SAMPLING: A METHOD FOR STUDYING GASEOUS FREE RADICALS
Science, **140,** 297 (1963)
Fristrom (1965)
Fristrom, R. M. and Westenberg, A. A.
Flame Structure, McGraw-Hill, New York (1965)
Fristrom (1972)
Fristrom, R. M.
FIRE AND FLAME STUDIES UTILIZING MOLECULAR BEAM SAMPLING
Molecular Beam Sampling Symposium, 25–27 (October 1972), Lake of the Ozarks, Mo.; Midwest Research Institute, Kansas City, MO

—G—

Gaydon (1957)
Gaydon, A. G.
The Spectroscopy of Flames, Chapman-Hall, London (1957)
Gordon (1959)
Gordon, A. S., Smith, S. R., and McNesby, J. R.
STUDY OF THE CHEMISTRY OF DIFFUSION FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 317 (1959)
Green (1963)
Green, J. A. and Sugden, T. M.
SOME OBSERVATIONS ON THE MECHANISM OF IONIZATION IN FLAMES CONTAINING HYDROCARBONS
Ninth Symposium (International) on Combustion, The Combustion Institute, 607 (1963)
Greene (1964)
Greene, F. T., Brewer, J., and Milne, T. A.
MASS SPECTROMETRIC STUDIES OF REACTIONS IN FLAMES: I. BEAM FORMATION AND MASS DEPENDENCE IN SAMPLING 1-ATOM GASES
J. Chem. Phys., **40,** 1488 (1964)
Grewer (1959)
Grewer, Th. and Wagner, H. Gg.
REACTION ZONE OF FLAMES
Z. Physik. Chem. (Frankfurt), **20,** 371 (1959)
Grewer (1960)
Grewer, Th., Bonne, U., and Wagner, H. Gg.

MESSUNGEN IN DER REAKTIONSZONE VON WASSERSTOFF-SAUERSTOFF UND METHAN-SAUERSTOFF FLAMMEN
Z. Physik. Chem. (Frankfurt), **26,** 93 (1960)

Grover (1963)
Grover, J. H., Fales, F. N., and Scurlock, A. C.
TURBULENT FLAME STUDIES IN TWO-DIMENSIONAL OPEN BURNERS
Ninth Symposium (International) on Combustion, The Combustion Institute, 21 (1963)

—H—

Hall (1957)
Hall, A. R. and Wolfhard, H. G.
MULTIPLE REACTION ZONES IN LOW-PRESSURE FLAMES WITH ETHYL AND METHYL NITRATE, METHYL NITRITE, AND NITROMETHANE
Sixth Symposium (International) on Combustion, The Combustion Institute, 190 (1957)

Hall (1959)
Hall, A. R.
EXPERIMENTAL TEMPERATURE GRADIENTS IN BURNING DROPS
Seventh Symposium (International) on Combustion, The Combustion Institute, 641 (1959)

Halstead (1969)
Halstead, C. J. and Jenkins, D. R.
RADICAL RECOMBINATION IN RICH PREMIXED HYDROGEN—OXYGEN FLAMES
Twelfth Symposium (International) on Combustion, The Combustion Institute, 979 (1969)

Hayhurst (1966)
Hayhurst, A. N. and Sugden, T. M.
MASS SPECTROMETRY OF FLAMES
Proc. Roy. Soc., **A293,** 36 (1966)

Hayhurst (1970)
Hayhurst, A. N. and Telford, N. R.
DIFFUSIONAL EFFECTS IN PREMIXED LAMINAR FLAMES OF HYDROGEN, OXYGEN, AND NITROGEN
Combustion and Flame, **14,** 303 (1970)

Heath (1967)
Heath, G. A. and Pearson, G. S.
PERCHLORIC ACID FLAMES: PART III. CHEMICAL STRUCTURE OF METHANE FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 967 (1967)

Heinsohn (1969)
Heinsohn, R. I., Thillard, S. V., and Becker, P. M.
TEMPERATURE PROFILES OF AN OPPOSED-JET DIFFUSION FLAME SUBJECTED TO AN ELECTRIC FIELD (Letter)
Combustion and Flame, **13,** 44 (1969)

Hicks (1962)
Hicks, J. A.
LOW PRESSURE DECOMPOSITION FLAME OF ETHYL NITRATE
Eighth Symposium (International) on Combustion, The Combustion Institute, 487 (1962)

Hinck (1965)
Hinck, E. C., Seamans, T. F., Vanpee, M., and Wolfhard, H. G.
THE NATURE OF OH RADIATION IN LOW-PRESSURE FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 21 (1965)

Homann (1963)
Homann, K. H., Machizi, M., and Wagner, H. Gg.
UBER DEN REAKTIONSABLUF IN FETTEN KOHLENWASSERSTOFFE-SAUERSTOFF-FLAMMEN I. [On the Reaction Mechanisms of Rich Hydrocarbon-Oxygen Flames]
Z. Physik. Chem., **37,** 299 (1963)

Homann (1965a)
Homann, K. H. and Wagner, H. Gg.
UNTERSUCHUNG DES REAKTIONSABLAUFS IN FETTEN KOHLENWASSERSTOFFE-SAUERSTOFFE-FLAMMEN: II. VERSUCHE AN RUSSENDEN ASCETYLEN-SAUERSTOFF-FLAMMEN DER NIEDRIGEM DRUCK
[Research on the Reaction Mechanism in Rich Hydrocarbon-Oxygen Flames: II. Studies on Smoky Acetylene-Oxygen Flames at Low Pressures]
Ber. Bunsenges. Phys. Chem., **69,** 20 (1965)

Homann (1965b)
Homann, K. H., MacLean, D. I., and Wagner, H. Gg.
INTERMEDIATES IN THE HYDRAZINE-DECOMPOSITION FLAME
Naturwissenschaften, **52,** 12 (1965) [in German]

Homann (1967)
Homann, K. H. and Wagner, H. Gg.
SOME NEW ASPECTS OF THE MECHANISMS OF CARBON FORMATION IN PREMIXED FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 371 (1967)

Homann (1968)
Homann, K. H. and Wagner, H. Gg.
CHEMISTRY OF CARBON FORMATION IN FLAMES
Proc. Roy. Soc., **A307,** 141–152 (1968)

Hottel (1953)
Hottel, H. C.
BURNING IN LAMINAR AND TURBULENT FUEL JETS
Fourth Symposium (International) on Combustion, The Combustion Institute, 97 (1953)

Hurle (1969)
Hurle, I. R., Sugden, T. M., and Nutt, G. B.
CHEMI-IONIZATION OF NITRIC OXIDE IN FLAMES CONTAINING HYDROCARBON ADDITIVES
Twelfth Symposium (International) on Combustion, The Combustion Institute, 387 (1969)

—J—

James (1953)
James, C. G. and Sugden, T. M.
RESONANCE RADIATION FROM HYDROGEN FLAMES CONTAINING ALKALI METALS
Nature, **171,** 428 (1953)

Jensen (1966)
Jensen, D. E. and Padley, P. J.

KINETICS OF IONIZATION OF THE ALKALI METALS IN $H_2 + O_2 + N_2$ FLAMES
Trans. Faraday Soc., **62**, 2140 (1966)
Jensen (1967)
Jensen, D. E. and Padley, P. J.
KINETIC STUDIES OF IONIZATION AND RECOMBINATION PROCESSES OF METALLIC ADDITIVES TO FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 351 (1967)
Jessen (1969)
Jessen, P. F. and Gaydon, A. G.
ESTIMATION OF CARBON RADICAL CONCENTRATIONS IN FUEL-RICH ACETYLENE—OXYGEN FLAMES BY ABSORPTION SPECTROSCOPY
Twelfth Symposium (International) on Combustion, The Combustion Institute, 481 (1969)

—K—

Kallend (1967)
Kallend, A. S.
INFLUENCE OF SO(2) ON CHEMILUMINESCENCE AND ATOM RECOMBINATION IN HYDROGEN FLAMES
Trans. Faraday Soc., **63**, 2442 (1967)
Kaskan (1958a)
Kaskan, W. E.
HYDROXYL CONCENTRATIONS IN RICH HYDROGEN-AIR FLAMES HELD ON POROUS BURNERS
Combustion and Flame, **2**, 229 (1958)
Kaskan (1958b)
Kaskan, W. E.
THE CONCENTRATION OF HYDROXYL AND OF OXYGEN ATOMS IN GASES FROM LEAN HYDROGEN-AIR FLAMES
Combustion and Flame, **2**, 286 (1958)
Kaskan (1959a)
Kaskan, W. E.
THE SOURCE OF THE CONTINUUM IN CARBON MONOXIDE—HYDROGEN—AIR FLAMES
Combustion and Flame, **3**, 39 (1959)
Kaskan (1959b)
Kaskan, W. E.
EXCESS RADICAL CONCENTRATIONS AND THE DISAPPEARANCE OF CARBON MONOXIDE IN FLAME GASES FROM SOME LEAN FLAMES
Combustion and Flame, **3**, 49 (1959)
Kaskan (1965)
Kaskan, W. E.
THE REACTION OF ALKALI ATOMS IN LEAN FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 41, (1965)
Kilham (1967)
Kilham, J. K. and Dunham, P. G.
ENERGY TRANSFER FROM CARBON MONOXIDE FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 899 (1967)

Kinbara (1954)
Kinbara, T. and Nakamura, J.
IONS IN DIFFUSION FLAMES
Sci. Papers Coll. Gen. Educ. Univ. Tokyo, **4**, 9 (1954)

Kinbara (1955)
Kinbara, T. and Nakamura, J.
THE IONS IN DIFFUSION FLAMES
Fifth Symposium (International) on Combustion, The Combustion Institute, 285 (1955)

Kinbara (1959)
Kinbara, T., Nakamura, J., and Ikegami, H.
DISTRIBUTION OF IONS IN LOW-PRESSURE FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 263 (1959)

King (1955)
King, I. R. and Calcote, H. F.
EFFECT OF PROBE SIZE ON ION CONCENTRATION MEASUREMENTS IN FLAMES
J. Chem. Phys., **23**, 2203 (1955)

Klaukens (1958)
Klaukens, H. and Wolfhard, H. G.
MEASUREMENTS IN THE REACTION ZONE OF A BUNSEN FLAME
Proc. Roy. Soc., **A193**, 512 (1958)

Klein (1968)
Klein, S., Guttinger, B., and Sahni, O.
FLAME TEMPERATURES IN PREMIXED FLAMES SUBJECTED TO AN ELECTRICAL FIELD
Compt. Rend. Acad. Sci. Paris, **B267**, 605 (1968)

Knewstubb (1956)
Knewstubb, P. F. and Sugden, T. M.
IONIZATION PRODUCED BY COMPOUNDS OF LEAD IN FLAMES
Research Correspondence, **9**, A1 (1956)

Knewstubb (1958a)
Knewstubb, P. F. and Sugden, T. M.
MASS SPECTROMETRIC OBSERVATIONS OF IONS IN FLAMES
Nature, **181**, 474 (1958)

Knewstubb (1958b)
Knewstubb, P. F. and Sugden, T. M.
MASS SPECTROMETRIC OBSERVATIONS OF IONS IN HYDROCARBON FLAMES
Nature, **181**, 1261 (1958)

Knewstubb (1958c)
Knewstubb, P. F. and Sugden, T. M.
OBSERVATIONS ON THE KINETICS OF IONIZATION OF ALKALI METALS IN FLAME GASES
Trans. Faraday Soc., **54**, 372 (1958)

Knewstubb (1959)
Knewstubb, P. F. and Sugden, T. M.
MASS SPECTROMETRY OF THE IONS PRESENT IN HYDROCARBON FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 247 (1959)

Knewstubb (1960)
Knewstubb, P. F. and Sugden, T. M.

MASS SPECTROMETRIC STUDIES OF IONIZATION IN FLAMES: I. THE SPECTROMETER AND ITS APPLICATION TO IONIZATION IN HYDROGEN FLAMES
Proc. Roy. Soc., **A255,** 520 (1960)

Kushida (1959)
Kushida, R. and Wohl, K.
SPECTROPHOTOMETRC STUDIES OF LAMINAR FLAMES: II. THE FLAME FRONT
Seventh Symposium (International) on Combustion, The Combustion Institute, 221 (1959)

—L—

Lapp (1972)
Lapp, M., Goldman, L. M., and Penny, C. M.
RAMAN SCATTERING FROM FLAMES
Science, **175,** 1112 (1972)

Lawton (1964)
Lawton, J. and Weinberg, F. J.
MAXIMUM ION CURRENTS FROM FLAMES AND THE MAXIMUM PRACTICAL EFFECTS OF APPLIED ELECTRIC FIELDS
Proc. Roy. Soc., **277,** 468 (1964)

Leah (1953)
Leah, A. S. and Carpenter, H.
THE ESTIMATION OF ATOMIC OXYGEN IN OPEN FLAMES AND THE MEASUREMENT OF TEMPERATURE
Fourth Symposium (International) on Combustion, The Combustion Institute, 274 (1953)

Levy (1959a)
Levy, A. and Weinberg, F. J.
OPTICAL FLAME STRUCTURE STUDIES: EXAMINATION OF REACTION RATE LAWS IN LEAN ETHYLENE—AIR FLAMES
Combustion and Flame, **3,** 229 (1959)

Levy (1959b)
Levy, A. and Weinberg, F. J.
OPTICAL FLAME STRUCTURE STUDIES: SOME CONCLUSIONS CONCERNING THE PROPAGATION OF FLAT FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 296 (1959)

Levy (1962)
Levy, A., Droege, J. W., Tighe, J. J., and Foster, J. F.
INHIBITION OF LEAN METHANE FLAMES
Eighth Symposium (International) on Combustion, The Combustion Institute, 524 (1962)

Levy (1965)
Levy, A. and Merryman, E. L.
THE MICROSTRUCTURE OF HYDROGEN SULPHIDE FLAMES
Combustion and Flame, **9,** 239 (1965)

Lewis (1943)
Lewis, B. and Von Elbe, G.
STABILITY AND STRUCTURE OF BURNER FLAMES
J. Chem. Phys., **11,** 75 (1943)

—M—

MacLean (1967)
MacLean, D. T. and Wagner, H. Gg.
THE STRUCTURE OF THE REACTION ZONES OF AMMONIA-OXYGEN AND HYDRAZINE-DECOMPOSITION FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 596 (1959)

Markstein (1959)
Markstein, G. H.
COMPOSITION TRAVERSES IN CURVED LAMINAR FLAME FRONTS
Seventh Symposium (International) on Combustion, The Combustion Institute, 596 (1959)

McAndrew (1962)
McAndrew, R. and Wheeler, R.
THE RECOMBINATION OF ATOMIC HYDROGEN IN PROPANE FLAME GASES
J. Phys. Chem., **66,** 229 (1962)

Merryman (1971)
Merryman, E. L. and Levy, A.
SULFUR TRIOXIDE FLAME CHEMISTRY—H_2S AND COS FLAMES
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 427 (1971)

Miller (1964)
Miller, W. J. and Calcote, H. F.
NEGATIVE-ION FORMATION IN HYDROCARBON FLAMES
J. Chem. Phys., **41,** 4001 (1964)

Miller (1967)
Miller, W. J.
LOW-PRESSURE FLAME COMPOSITION AND THE ORIGIN OF $C_3H_3^+$
Eleventh Symposium (International) on Combustion, The Combustion Institute, 311 (1967)

Miller (1968)
Miller, W. J.
IONIZATION IN COMBUSTION PROCESSES
Oxid. Combust. Rev., **3,** 97 (1968)

Milne (1965)
Milne, T. A. and Greene, F. T.
MASS-SPECTROMETRIC SAMPLING OF 1-ATM FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 153 (1965)

Milne (1966)
Milne, T. A. and Greene, F. T.
MASS-SPECTROMETRIC STUDIES OF REACTIONS IN FLAMES: II. QUANTITATIVE SAMPLING OF FREE RADICALS FROM ONE-ATMOSPHERE FLAMES
J. Chem. Phys., 44, 2444 (1966)

Minkoff (1963)
Minkoff, G. J. and Tipper, C. F. H.
Chemistry of Combustion Reactions
Butterworths, London (1963)

Mukunda (1971)
Mukunda, H. S., Maranthe, A. G., and Ramani, N.

ANALYSIS OF VARIATION OF THERMODYNAMIC AND TRANSPORT PROPERTIES IN FLAMES
First National Heat and Mass Transfer Conference, xii-47, Indian Institute of Technology, Madras, India (December 1971)

—O—

Orloff (1971)
Orloff, L. and De Ris, J.
MODELING CEILING FIRES
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 979 (1971)

—P—

Padley (1959a)
Padley, P. J. and Sugden, T. M.
CHEMILUMINESCENCE AND RADICAL RECOMBINATION IN HYDROGEN FLAMES
Seventh Symposium (International) on Combustion, The Combustion Institute, 235 (1959)

Padley (1959b)
Padley, P. J. and Sugden, T. M.
DETERMINATION OF THE DISSOCIATION CONSTANTS AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY: Part VI. STABILITIES OF MnO AND MnOH AND THEIR MECHANISMS OF FORMATION
Trans. Faraday Soc., **55,** 2054 (1959)

Padley (1961)
Padley, P. J., Page, F. M., and Sugden, T. M.
EFFECT OF HALOGENS ON THE IONIZATION IN ALKALI LADEN HYDROGEN AND ACETYLENE FLAMES. Part I. THE THEORY OF STEADY STATE IONIZATION IN FLAMES
Trans. Faraday Soc., **57,** 1522 (1961)

Padley (1962)
Padley, P. J. and Sugden, T. M.
SOME OBSERVATIONS ON THE PRODUCTION AND RECOMBINATION OF IONS AND ELECTRONS FROM METALLIC ADDITIVES IN HYDROGEN AND HYDROCARBON FLAMES
Eighth Symposium (International) on Combustion, The Combustion Institute, 164 (1962)

Page (1957)
Page, F. M. and Sugden, T. M.
THE MECHANISM OF THE IONIZATION OF ALKALI METALS IN HYDROGEN FLAMES
Trans. Faraday Soc., **53,** 1092 (1957)

Page (1958)
Page, F. M.
INFLUENCE DU SOUFRE SUR L'IONIZATION DES METAUX ALCALINS DANS UNE FLAMME D'HYDROGENE ET D'AIR
Revue de l'Institute Francaise du Petrole, **13,** No. 4, 692 (1958)

Page (1959)
Page, F. M. and Sugden, T. M.
BOND ENERGIES OF SOME ALKALI FLUORIDES
Nature, **183,** 1672 (1959)

Page (1960)
Page, F. M.
DETERMINATION OF ELECTRON AFFINITIES BY THE METHOD OF MAYER: I. EXPERIMENTAL TECHNIQUE AND INTEGRATION
Trans. Faraday Soc., **56,** 1742 (1960)

Page (1961a)
Page, F. M.
DETERMINATION OF ELECTRON AFFINITIES: II. ELECTRON AFFINITY OF THE OXYGEN ATOM
Trans. Faraday Soc., **57,** 359 (1961)

Page (1961b)
Page, F. M.
DETERMINATION OF ELECTRON AFFINITIES: III. AMINO RADICAL
Trans. Faraday Soc., **57,** 1254 (1961)

Page (1962)
Page, F. M. and Ansdell, D. A.
DETERMINATION OF ELECTRON AFFINITIES: IV. ELECTRON AFFINITIES OF THE SULFHYDRYL RADICAL AND THE SULFUR ATOM
Trans. Faraday Soc., **58,** 1084 (1962)

Pandya (1963)
Pandya, T. P. and Weinberg, F. J.
THE STUDY OF THE STRUCTURE OF LAMINAR DIFFUSION FLAMES BY OPTICS
Ninth Symposium (International) on Combustion, The Combustion Institute, 587 (1963)

Pandya (1964)
Pandya, T. P. and Weinberg, F. J.
THE STRUCTURE OF FLAT, COUNTER-FLOW DIFFUSION FLAMES
Proc. Roy. Soc., **A279,** 544 (1964)

Panfilov (1962)
Panfilov, V. N.
H-ATOMS IN THE REACTION ZONE OF H_2–FLAMES
Kinetika i Kataliz [Kinetics and Catalysis], **3,** 643 (1962)

Patel (1970)
Patel, N. K. and Chu, C.
STUDIES OF OPPOSED JET DIFFUSION FLAMES: I. TEMPERATURE DISTRIBUTION
Combustion and Flame, **14,** 137 (1970)

Payne (1959)
Payne, K. G. and Weinberg, F. J.
A PRELIMINARY INVESTIGATION OF FIELD-INDUCED ION MOVEMENT IN FLAME GASES AND ITS APPLICATIONS
Proc. Roy. Soc., **A250,** 316 (1959)

Payne (1962)
Payne, K. G. and Weinberg, F. J.
MEASUREMENT OF FIELD-INDUCED ION FLOW FROM PLANE FLAMES
Eighth Symposium (International) on Combustion, The Combustion Institute, 207 (1962)

Peacock (1962)
Peacock, F. and Weinberg, F. J.

METHODS FOR THE STUDY OF HYDROGEN-BROMINE FLAME KINETICS
Eighth Symposium (International) on Combustion, The Combustion Institute, 458 (1962)

Peeters (1969)
Peeters, J., Vinckier, C., and Van Tiggelen, A.
FORMATION AND BEHAVIOR OF CHEMI-IONS IN FLAMES
Oxid. Combust. Rev., **4,** 93 (1969)

Phillips (1960)
Phillips, L. F. and Sugden, T. M.
SOME OBSERVATIONS ON THE RADIATIVE COMBINATION OF ATOMIC HYDROGEN WITH ATOMIC HALOGENS IN BURNER FLAMES
Can. J. Chem., **38,** 1804 (1960)

Phillips (1961a)
Phillips, L. F. and Sugden, T. M.
DETERMINATION OF DISSOCIATION CONSTANTS AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY: Part 7. FLAME PHOTOMETRIC STUDY OF THE IO RADICAL
Trans. Faraday Soc., **57,** 914 (1961)

Phillips (1961b)
Phillips, L. F. and Sugden, T. M.
SOME RATE CONSTANTS FOR TERMOLECULAR EXCITATION REACTIONS OF ATOMS IN FLAMES
Trans. Faraday Soc., **57,** 2188 (1961)

Porter (1967)
Porter, R. P., Clark, A. H., Kaskan, W. E., and Browne, W. E.
A STUDY OF HYDROCARBON FLAMES
Eleventh Symposium (International) on Combustion, The Combustion Institute, 907 (1967)

Powling (1957)
Powling, J. and Smith, W. A. W.
DECOMPOSITION FLAMES OF THE PROPYL NITRATES
Combustion and Flame, **1,** 308 (1957)

Powling (1958)
Powling, J. and Smith, W. A. W.
THE COMBUSTION OF BUTANE-2,3 and 1,4-DIOL DINITRATES AND SOME ALDEHYDE-NO(2) MIXTURES
Combustion and Flame, **2,** 157 (1958)

Powling (1960)
Powling, J., Smith, W. A. W., and Thynne, J.
THE FLAME DECOMPOSITION OF SOME SUBSTITUTED ETHYL NITRATES
Combustion and Flame, **4,** 201 (1960)

Pownall (1971)
Pownall, C. and Simmons, R. F.
THE EFFECT OF HYDROGEN BROMIDE ON THE STRUCTURE OF PROPANE-OXYGEN FLAMES DILUTED WITH ARGON
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 585 (1971)

Prescott (1954)
Prescott, R., Hudson, R., Foner, S., and Avery, W. H.
COMPOSITION PROFILES IN PREMIXED LAMINAR FLAMES
J. Chem. Phys., **22,** 145 (1954)

—R—

Rapp (1960)
Rapp, D. and Johnston, H. S.
NO-F(2) DILUTE DIFFUSION FLAME
J. Chem. Phys., **33,** 695 (1960)

Reck (1956)
Reck, J., Sumi, K., and Weinberg, F. J.
AN OPTICAL METHOD OF FLAME MEASUREMENT: II. SENSITIVITY AND MEASUREMENTS
Fuel, **35,** 364 (1956)

Reid (1962)
Reid, R. W. and Sugden, T. M.
ELECTRONIC EXCITATION OF METALLIC HYDROXIDES IN HYDROGEN FLAME GASES
Disc. Faraday Soc., **33,** 213 (1962)

Rosenfeld (1964a)
Rosenfeld, J. L. J. and Sugden, T. M.
BURNING VELOCITY AND FREE RADICAL RECOMBINATION RATES IN LOW TEMPERATURE H_2 FLAMES: I. MEASUREMENT OF TEMPERATURE AND BURNING VELOCITY
Combustion and Flame, **8,** 44 (1964)

Rosenfeld (1964b)
Rosenfeld, J. L. J. and Sugden, T. M.
BURNING VELOCITY AND FREE RADICAL RECOMBINATION RATES IN LOW TEMPERATURE H_2 FLAMES: II. RATE CONSTANTS FOR RECOMBINATION REACTIONS
Combustion and Flame, **8,** 44 (1964)

—S—

Sachsse (1937)
Sachsse, H.
THE TEMPERATURE DEPENDENCE OF THE FLAME VELOCITY AND THE TEMPERATURE FALL IN THE FOREPART OF A FLAME
Z. Physik. Chem., **180A,** 305 (1937)

Singh (1971)
Singh, T. and Sawyer, R. F.
CO-REACTIONS IN THE AFTERFLAME REGION OF ETHYLENE—OXYGEN AND ETHANE—OXYGEN FLAMES
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 403 (1971)

Smith (1952a)
Smith, H. and Sugden, T. M.
STUDIES ON THE IONIZATION PRODUCED BY METALLIC SALTS IN FLAMES: III. IONIC EQUILIBRIA IN HYDROGEN—AIR FLAMES CONTAINING ALKALI METALS
Proc. Roy. Soc., **A211,** 31 (1952)

Smith (1952b)
Smith, H. and Sugden, T. M.
STUDIES ON THE IONIZATION PRODUCED BY METALLIC SALTS IN FLAMES: IV. THE STABILITY OF GASEOUS ALKALI HYDROXIDES IN FLAMES
Proc. Roy. Soc., **A211,** 58 (1952)

Smith (1953)
Smith, H. and Sugden, T. M.
THE STABILITY OF GASEOUS LITHIUM HYDROXIDE AT HIGH TEMPERATURES AND ITS RELATION WITH THE HYDROXYL CONCENTRATION OF FLAME GASES
Proc. Roy. Soc., **A219,** 204 (1953)

Smith (1954)
Smith, S. R. and Gordon, A. S.
PRECOMBUSTION REACTIONS IN HYDROCARBON DIFFUSION FLAMES: THE PARAFFIN CANDLE FLAME
J. Chem. Phys., **22,** 1150 (1954)

Smith (1956a)
Smith, S. R. and Gordon, A. S.
STUDIES OF DIFFUSION FLAMES: I. THE METHANE DIFFUSION FLAME
J. Phys. Chem., **60,** 759 (1956)

Smith (1956b)
Smith, S. R. and Gordon, A. S.
STUDIES OF DIFFUSION FLAMES: II. DIFFUSION FLAMES OF SOME SIMPLE ALCOHOLS
J. Phys. Chem., **60,** 1069 (1956)

Smith (1958)
Smith, S. R. and Gordon, A. S.
STUDIES OF DIFFUSION FLAMES: III. THE DIFFUSION FLAMES OF THE BUTANOLS
J. Phys. Chem., **61,** 553 (1958)

Spokes (1957)
Spokes, G. N. and Gaydon, A. G.
ABSORPTION SPECTRA OF FLAT FLAMES USING A MULTIPLE REFLECTION TECHNIQUE
Nature, **180,** 114 (1957)

Sugden (1954)
Sugden, T. M., Bulewicz, E. M., and James, C. G.
PHOTOMETRIC INVESTIGATIONS OF ALKALI METALS IN HYDROGEN FLAME GASES: I. A GENERAL SURVEY OF THE USE OF RESONANCE RADIATION IN THE MEASUREMENT OF ATOMIC CONCENTRATIONS
Proc. Roy. Soc., **A227,** 312 (1954)

Sugden (1955a)
Sugden, T. M.
THE USE OF MICROWAVES IN THE STUDY OF IONIC AND CHEMICAL EQUILIBRIA AT HIGH TEMPERATURES
Disc. Faraday Soc., **19,** 68 (1955)

Sugden (1955b)
Sugden, T. M. and Wheeler, R. C.
THE IONS PRODUCED BY TRACES OF ALKALINE EARTHS IN HYDROGEN FLAMES
Disc. Faraday Soc., **19,** 76 (1955)

Sugden (1955c)
Sugden, T. M.
MICROWAVE STUDIES IN THE IONIZATION OF ALKALI METALS IN FLAME GASES AND RELATED PHENOMENA
Fifth Symposium (International) on Combustion, The Combustion Institute, 406 (1955)

Sugden (1956a)
Sugden, T. M., Knewstubb, P. F., and Smith, K. F.
MASS SPECTROMETRIC DETECTION OF THE ION $(SrOH)^+$
Nature, **178**, 693 (1956)

Sugden (1956b)
Sugden, T. M.
DETERMINATION OF THE DISSOCIATION AND HEATS OF FORMATION OF MOLECULES BY FLAME PHOTOMETRY: Part I. EQUILIBRIUM IN FLAME GASES AND GENERAL KINETIC CONSIDERATIONS
Trans. Faraday Soc., **52**, 1465 (1956)

Sugden (1958)
Sugden, T. M.
APPLICATION OF QUANTITATIVE FLAME PHOTOMETRY TO THE STUDY OF COMBUSTION
Rev. Inst. France Petrole et Ann. Combustibles Liquides, **13**, 629 (1958)

Sugden (1962a)
Sugden, T. M.
EXCITED SPECIES IN FLAMES
Ann. Rev. Phys. Chem., **13**, 369 (1962)

Sugden (1962b)
Sugden, T. M., Bulewicz, E. M., and Demerdache, A.
SOME OBSERVATIONS ON OXIDES AND HYDRIDES OF NITROGEN AND SULFUR IN FLAME GASES CONTAINING ATOMIC HYDROGEN, ATOMIC OXYGEN, AND HYDROXYL RADICALS
Chemical Reactions in the Lower and Upper Atmosphere, Interscience Press, Inc., New York, 89 (1962)

Sugden (1962c)
Sugden, T. M. and Knewstubb, P. F.
MASS-SPECTROMETRIC OBSERVATIONS OF NEGATIVE IONS IN FLAME GASES
Nature, **196**, 1311 (1962)

Sugden (1962d)
Sugden, T. M.
A SURVEY OF FLAME IONIZATION WORK AT THE UNIVERSITY OF CAMBRIDGE
Prog. Astronaut. Aeron., **12**, 145 (1962)

Sugden (1962e)
Sugden, T. M.
THE SPECTROPHOTOMETRY OF FREE RADICALS IN FLAMES
Spectroscopy, Institute of Petroleum Symposium, 137 (1962)

—T—

Tewari (1967)
Tewari, G. P. and Weinberg, F. J.
STRUCTURE OF FLAME QUENCHED BY COLD SURFACES
Proc. Roy. Soc., **A296**, 546 (1967)

Tsuji (1970)
Tsuji, H. and Hirano, T.
ION CONCENTRATION DISTRIBUTIONS IN TWO-DIMENSIONAL NOZZLE BURNER FLAMES AT ATMOSPHERIC PRESSURE
Combustion and Flame, **15**, 47 (1970)

Tsuji (1971)
Tsuji, H. and Yamaoka, I.
STRUCTURE ANALYSIS OF COUNTERFLOW DIFFUSION FLAMES IN THE FORWARD STAGNATION REGION OF A POROUS CYLINDER
Thirteenth Symposium (International) on Combustion, The Combustion Institute, 723 (1971)

—V—

Van Tiggelen (1962)
Van Tiggelen, A.
IONIZATION PHENOMENA IN FLAMES
Prog. Astronaut. Aeron., **12,** 165–196 (1962)

—W—

Wagner (1961)
Wagner, H. Gg.
STABILITY AND PROPAGATION OF FLAMES
Z. Elektrochem., **65,** 290 (1961)

Ward (1962)
Ward, F. J. and Weinberg, F. J.
PHOTOGRAPHIC RECORDING OF SLOW IONS FROM FLAMES
Eighth Symposium (International) on Combustion, The Combustion Institute, 217 (1962)

Weinberg (1954)
Weinberg, F. J.
THE SHADOWGRAPH OF A FLAT FLAME
Proc. Roy. Soc., **A235,** 71 (1954)

Weinberg (1955)
Weinberg, F. J.
LOCATION OF THE SCHLIEREN IMAGE IN A FLAME
Fuel, Supplement S. 84, 34 (1955)

Weinberg (1956a)
Weinberg, F. J.
LOCATION OF THE SCHLIEREN IMAGE IN A FLAME—2-DIMENSIONAL FLAMES
Fuel, **35,** 161 (1956)

Weinberg (1956b)
Weinberg, F. J.
AN OPTICAL METHOD OF FLAME TEMPERATURE MEASUREMENT: I. THEORY
Fuel, **35,** 359 (1956)

Weinberg (1957a)
Weinberg, F. J.
THE ROLE OF FLAME STRUCTURE STUDIES IN THE INVESTIGATION OF HIGH TEMPERATURE CHEMICAL KINETICS
A. R. C., **19,** 293, C. F. 401 (1957)

Weinberg (1957b)
Weinberg, F. J.
THE THICKNESS OF LAMINAR FLAMES IN PREMIXED REACTANTS
Proc. Roy. Soc., **A243,** 107 (1957)

Weinberg (1957c)
Weinberg, F. J.
APPLICATION OF OPTICAL METHODS TO COMBUSTION RESEARCH
Sixth Symposium (International) on Combustion, The Combustion Institute, 765 (1957)

Weinberg (1961)
Weinberg, F. J.
GEOMETRIC-OPTICAL TECHNIQUES IN COMBUSTION RESEARCH
Progress in Combustion Science and Technology, Pergamon Press, London (1961)

Weinberg (1963)
Weinberg, F. J.
The Optics of Flames and Methods for the Study of Refractive Index Fields in Gases
Butterworth and Co., Ltd., London (1963)

Westenberg (1957)
Westenberg, A. A., Raezer, S. D., and Fristrom, R. M.
INTERPRETATION OF THE SAMPLE TAKEN BY A PROBE IN A LAMINAR CONCENTRATION GRADIENT
Combustion and Flame, **1**, 467 (1957)

Westenberg (1960)
Westenberg, A. A. and Fristrom, R. M.
METHANE-OXYGEN FLAME STRUCTURE: II. CONSERVATION OF MATTER AND ENERGY IN THE ONE-TENTH ATMOSPHERE FLAME
J. Phys. Chem., **64**, 1393 (1960)

Westenberg (1961)
Westenberg, A. A. and Fristrom, R. M.
METHANE—OXYGEN FLAME STRUCTURE: IV. CHEMICAL KINETIC CONSIDERATIONS
J. Phys. Chem., **65**, 591 (1961)

Westenberg (1965)
Westenberg, A. A. and Fristrom, R. M.
H AND O ATOM PROFILES MEASURED BY ESR IN C(2)-HYDROCARBON-O(2) FLAMES
Tenth Symposium (International) on Combustion, The Combustion Institute, 4737 (1965)

Williams (1957)
Williams, H.
THE PREDOMINANT PROCESS OF ELECTRON DECAY IN THE MANTLE OF AN ACETYLENE—AIR FLAME
Seventh Symposium (International) on Combustion, The Combustion Institute, 269 (1957)

Williams (1962)
Williams, H.
FURTHER STUDIES ON THE DECAY OF FREE ELECTRONS IN THE MANTLE OF AN ACETYLENE—AIR FLAME
Eighth Symposium (International) on Combustion, The Combustion Institute, 179 (1962)

Wilson (1963)
Wilson, W. E., Jr., and Fristrom, R. M.
RADICALS IN FLAMES
APL Tech. Digest, **2**, 2 (1963)

Wilson (1965)
Wilson, W. E., Jr.
STRUCTURE, KINETICS, AND MECHANISMS OF A METHANE—OXYGEN FLAME INHIBITED WITH METHYL BROMIDE
Tenth Symposium (International) on Combustion, The Combustion Institute, 47 (1965)

Wohl (1955)
Wohl, K. and Welty, F.
SPECTROPHOTOMETRIC TRAVERSES THROUGH FLAME FRONTS
Fifth Symposium (International) on Combustion, The Combustion Institute, 746 (1955)

Wohl (1958)
Wohl, K.
OPTICAL STUDIES OF THE STRUCTURE OF TURBULENT FLAMES
Z. Physik. Chem. (Frankfurt), **16,** 387 (1958)

Wolfhard (1949)
Wolfhard, H. G. and Parker, W. G.
A NEW TECHNIQUE FOR THE SPECTROSCOPIC EXAMINATION OF FLAMES AT NORMAL PRESSURES
Proc. Phys. Soc., **62A,** 722 (1949)

Wolfhard (1952a)
EXPERIMENTAL INVESTIGATION OF INTERNAL STRUCTURE OF FLAMES
AGARD Report AG 5-P2, 9 (1952)

Wolfhard (1952b)
Wolfhard, H. G. and Parker, W. G.
A SPECTROSCOPIC INVESTIGATION INTO THE STRUCTURE OF DIFFUSION FLAMES
Proc. Phys. Soc. (London), **65A,** 2 (1952)

Wortberg (1965)
Wortberg, G.
ION–CONCENTRATION MEASUREMENTS IN A FLAT FLAME AT ATMOSPHERIC PRESSURE
Tenth Symposium (International) on Combustion, The Combustion Institute, 651–655 (1965)

—Y—

Yumlu (1966)
Yumlu, V. S.
TEMPERATURE OF FLAMES ON POROUS BURNERS
Combustion and Flame, **10,** 147 (1966)

—Z—

Zeegers (1965)
Zeegers, P. J. Th. and Alkemade, C. Th. J.
RADICAL RECOMBINATIONS IN ACETYLENE—AIR FLAMES
Combustion and Flame, **9,** 847 (1965)

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ABSTRACTS AND REVIEWS

A. Prevention of Fires and Fire Safety Measures

Collins, J. R. "Flame Resistant Fibres," *Paper No. 11, Conference on Plastics in Fire,* I. E. E., London, England (November 1971)

Subjects: Flame-resistant fibers; Fibers; Polymers; Retardants

Reprint of Safety in Mines Research
Establishment Abstract, By Permission

The wide range of conditions calling for the use of flame-resistant fibres is outlined, and the factors involved in selecting suitable fibres are considered. These factors include not only flame resistance but also cost and textile performance. The degree to which existing nonsynthetic and bulk-produced synthetic fibres can match, or can be made to match, these requirements is considered. The main part of the paper describes those fibres which are inherently flame resistant by virtue of their chemical structure. These fibres fall into two groups, the high-temperature-resistant fibres and the highly chlorinated fibres. The high-temperature-resistant fibres have the higher flame resistance; they also have a more restricted textile performance and are more costly. The highly chlorinated fibres, such as the polyvinyl chloride, modacrylic and polychal fibres, have an adequate flame resistance for many conditions and give a more versatile textile performance at a cost similar to that of the bulk-produced synthetics.

Heinrich, H. J. "Technical Problems in the Determination of the Safety Parameters of Flammable Dusts," *International Symposium on Dust Explosion Risks in Mines and Industry,* Karlovy Vary, Czechoslovakia (October 11-13, 1972) (in German)

Subjects: Dusts, clouds and layers; Flammable dusts; Ignition; Clouds of dust

Reprint of Safety in Mines Research
Establishment Abstract, By Permission

The fundamental problems arising at the determination of safety data for inflammable dust clouds and dust layers as well as the limits of applicability on questions concerning safety engineering are dealt with. The following data are discussed in detail: Normal burning velocity, maximum explosion pressure, maximum rate of pressure rise, lower limit of explosibility, minimum energy of ignition, self-ignition temperature and ignition temperature of a dust layer. 11 refs., 17 figs., 2 tables.

Hobson, P. J. and Stewart, L. J. (Joint Fire Research Organization, Borehamwood, Herts., England) "Pressurisation of Escape Routes in Buildings," *Joint Fire Research Organization Fire Note No. 958* (December 1972)

Subjects: Escape means; Pressurization; Building; Smoke; Movement, Air

Authors' Summary

This paper reports results of studies made to provide specific design requirements for mechanical ventilation systems (often called "pressurisation" systems) for keeping escape routes in buildings clear of smoke and toxic gases.

The contract was placed and originally supervised by the Directorate of Research and Information of the Ministry of Public Building and Works, supervision being transferred to the Fire Research Station following the creation of the Department of the Environment.

Mallinder, R. (Safety in Mines Research Establishment, Sheffield, England) "Phosphorus Compounds as Flame Retardants for Plastics," *Paper No. 12, Conference on Plastics in Fire*, I. E. E., London, England (November 1971) (13 pages) See **Section H.**

Nakata, K. and Yamashita, K. (Fire Research Institute of Japan, Tokyo, Japan) "Study of the Check of the Smoke by Air Curtain," *Report of the Fire Research Institute of Japan No. 34*, p. 12 (September 1971) (in Japanese)

Subjects: Smoke; Air curtain

Authors' Abstract

This study was taken up to develop the method of securing the escape-route from fire. The purpose is to investigate the possibility of the prevention of smoke from spreading through corridors by taking advantage of air curtain in place of fire-proof doors. At first in this paper, it was ascertained that simple air curtain couldn't check the spreading of smoke but push-pull air curtain was able to effect our aim.

Next, we gave the design data for air curtain enough to check the smoke successfully. It was also clarified that heat transfer by convection from fire was astonishingly removed by the air curtain.

Rae, D. (Safety in Mines Research Establishment, Sheffield, England) "Experimental Coal-Dust Explosions in the Buxton Full-Scale Surface Gallery. VII—An Examination of Water-Trough Barriers," *Safety in Mines Research Establishment Research Report 284* (1973)

Subjects: Explosions; Mine safety; Water troughs; Buxton gallery

Author's Preface and Summary

This is the seventh paper reporting on the work done in the Buxton 366 m gallery and describes 80 experiments on the suppression of explosions by water barriers done between April 1968 and December 1969 in among other experiments on triggered barriers not described here.

Barriers are assessed for effectiveness by considering the influence they have on the development of explosion pressure as well as on flame extent. Various arrangements of water containers on the timber frame of the standard light stone–dust barrier have been tried. An assessment based on a total of eighty explosions of 10 and 50 per cent inert dusts, with both fast and slow–acting initiations, shows that the minimum distance at which such a barrier is effective in mostly determined by which type of initiation is used. The open–trough barrier of earlier work has been modified by fitting lids to prevent evaporation, and a more practical barrier has been evolved which has fewer larger containers on fewer shelves, but which is as effective as the present light stone–dust barrier.

Ushakov, K., Puchkov, L., and Silaev, V. "A Method of Assessing Aerodynamic Conditions Making for Fire Hazards in Coal Wastes," *Fourteenth International Conference of Mine-Safety Research Establishments*, Donetsk, U.S.S.R. (1971) (in Russian) (SMRE Translation No. 6119)

Subjects: Fire hazards; Hazards; Coal wastes

Safety in Mines Research Establishment Abstract, by Permission

Fire hazard of wastes containing coal liable to spontaneous combustion depends on the filtration air flow intensity which is, in general, volume-distributed. To evaluate the intensity distribution for waste filtration flows in the steep thick seams of the Kuzbass the aero-flow resistances have been studied, methods to determine air leakages during any filtration regime have been developed, and the volume distribution of the filtration rate has been analysed. This makes it possible to detect fire hazard zones (from the aerodynamic point of view) and evaluate the effectiveness of fire protection.

B. Ignition of Fires

Curcic, A. and Vukanovic, B. "Results of Dust Explosibility Tests on Coal from Yugoslavian Coal Mines," *International Symposium on Dust Explosion Risks in Mines and Industry,* Karlovy Vary, Czechoslovakia (October 11-13, 1972) (in German)

Subjects: Explosibility; Dust; Tests

Safety in Mines Research Establishment
Abstract, By Permission

The authors describe tests on the physical and chemical properties and on the incendivity and dispersability of coal-dusts and give results of analysis of four different types of coal. 8 figs., 6 tables.

Phillips, H. (Safety in Mines Research Establishment, Buxton, Derbyshire, England) "Ignition in a Transient Turbulent Jet of Hot Inert Gas," *Combustion and Flame* **19,** 187 (1972)

Subjects: Ignition; Turbulence; Inert gas, ignition by; Thermal ignition

Author's Abstract

The ignition mechanism described by Phillips is applied to the ignition of a flammable fuel/air mixture by a transient jet of hot inert gas. Calculated minimum jet sizes for ignition for a number of fuels were compared with the maximum experimental safe gap for a flameproof enclosure. To make the comparison, the rate of entrainment into a transient jet was estimated. The critical gap size depends on jet velocity, but good agreement with experiment was found by taking the minimum critical gap size.

Raftery, M. M. "Ignition Properties of Dust/Air Mixtures—the Development of Explosibility Tests," *International Symposium on Dust Explosion Risks in Mines and Industry,* Karlovy Vary, Czechoslovakia (October 11-13, 1972)

Subjects: Explosibility tests; Tests of dust explosibility; Dust

Safety in Mines Research Establishment
Abstract, By Permission

The ignition properties of dust/air mixtures and measurement of explosion parameters for dusts from small-scale tests are discussed, with the practical application of test results to those from larger-scale research and industrial plant being considered. Experiments in small-scale tests and larger-scale plant have shown good agreement over the range of dusts investigated. 5 refs., 7 figs., 2 tables.

Thomas, P. H. (Joint Fire Research Organization, Borehamwood, Herts., England) "Self-Heating and Thermal Ignition—A Guide to Its Theory and Application," *Ignition, Heat Release, and Non-combustibility of Materials, ASTM STP 502,* pp. 56–82, American Society for Testing and Materials (1972)

Subjects: Fires; Flammability; Ignition; Heating; Combustion; Thermal properties; Thermal stability; Building codes; Construction materials

Author's Summary

Some of the important theoretical aspects of self-heating and thermal ignition theory have been summarized briefly. Note, however, that equations quoted do not necessarily represent the correct form for analysis, rather, they have been idealized to show as clearly as necessary the physical principles involved. Thus, any reader need not be reminded to refer to more detailed treatises. The essential results of the discussion can be summarized as follows:

1. It is often possible to derive theoretical and experimental ignition temperatures for materials, but these refer to the environment as well as to the material. They are properties of shape and the heat transfer conditions.

2. Experiments on ignition (thermal instability) can usually be correlated by simple formulas or tested against one which uses a nominal or effective activation energy E. Extrapolation is possible as a first approximation in the absence of evidence to the contrary.

3. Values of the induction time can be related to size. This is a test of one aspect of the physical mathematical model, as is the effect of preheating on induction time and ignition.

4. The combustible content of materials on the borderline of combustibility

according to standard tests may well be high enough to produce substantial temperature rises or self-heating under bulk storage conditions.

5. Materials which self-heat can behave as perfect insulators at some stage in the growth of a fire; this could play an important role irrespective of the thermal content of the material itself. In other words, the acceptance of a material because it has a low effective thermal content does not mean that it *necessarily* can be regarded as *inert* in its contribution to the behavior of a fire.

C. Detection of Fires

Firth, J. G., Jones, A., and Jones, T. A. (Department of Trade and Industry, Safety in Mines Research Establishment, Sheffield, England) "The Principles of the Detection of Flammable Atmospheres by Catalytic Devices," *Combustion and Flame,* **21,** 303–311 (1973).

Subjects: Detection; Catalytic detectors; Flammable atmosphere detection

Author's Abstract

Most instruments used for measuring the explosibility of fuel/air atmospheres use catalytic oxidation as a method of measurement. The detailed mechanism of this method has been examined and equations describing the output from these devices have been derived. The output $V_{(LEL)}$ at the lower explosive limit of a fuel has the general form

$$V_{(LEL)} = K D_{12} \triangle H [LEL],$$

where D_{12}, $\triangle H$, and [LEL] are respectively the diffusion coefficient, heat of oxidation, and the lower explosive limit of the fuel in air, and K is a constant. Calculations have been made which enable the responses to explosive gas/air mixtures to be predicted and correction factors to be derived for practical devices. A new method for the measurement of explosiveness is discussed based on the empirical correlation between the heat of oxidation of the fuel and its lower explosive limit.

D. Propagation of Fires

Babkin, V. S. and V'ynn, A. V. (Novosibirsk, U.S.S.R.) "Mechanism of Laminar Flame Propagation at High Pressure," *Fizika Goreniya i Vzryva* **7**(2), 241–245 (June 1971) (in Russian)

Subjects: Burning velocities at high pressures; Pressure dependence of burning velocity; Inhibition; Methane—Air—Bromine flames; Bromine inhibition

Authors' Conclusions
Translated by L. Holtschlag

Experiments were carried out on the effect of bromine on the normal velocity of an 8.5% methane-air flame in the range of 1–70 atm in a spherical bomb with central ignition. The normal velocity was determined by the initial section method described earlier. Ampules with a specific weighed portion which were broken in the bomb by a special device were used to prepare the mixture with bromine. The degree of uniformity of the mixture was not checked, but was considered to be satisfactory from indirect observations. The experimental results are given in the form of the dependence of the ratio of the normal velocity with an admixture of inhibitor to the velocity without an admixture or the molar fraction of bromium in the mixture. Experiments with small admixtures of bromine showed that the reaction is a chain reaction in the methane-air flame up to 70 atm. Indirect confirmation is also obtained of the hypothesis that the temperature factor plays an increasing role with pressure increase, which is a necessary prerequisite of the thermal mechanism of flame propagation.

Campbell, A. S. (Department of Mechanical Engineering, University of Maine, Orono, Maine) "Some Burning Characteristics of Filter Paper," *Combustion Science and Technology* **3,** 103–120 (1971)

Subjects: Burning of filter paper; Filter paper burning

Author's Abstract

The downward rate of spread of a free-burning fire in a single piece of filter paper has been studied experimentally. The internal temperature distribution in the paper is calculated from a numerical solution of the two-dimensional heat conduction equation. Net heat flux from the flame can be computed, and a model for the burning zone tested by comparing measured and computed char zone lengths. Correlation is good, suggesting that a simple model of the pyrolysis process is valid.

Liebman, I., Corry, J., and Perlee, H. E. (Safety Research Center, Bureau of Mines, U. S. Department of the Interior, Pittsburgh, Pennsylvania) "Dynamics of Flame Propagation through Layered Methane—Air Mixtures," *Combustion Science and Technology* **2,** 365–375 (1971)

Subjects: Flame propagation; Layered methane—air

Author's Abstract

Characteristics of flames propagating in vertical tubes in the direction of steep methane-air concentration gradients of about 1.3 volume-percent methane per cm were investigated using interferometric techniques. The maximum flame velocity for upward and downward propagation in both 2.5- and 5.0-cm diameter tubes occurred in the fuel-rich region; lower flame speeds were observed with the smaller tube diameter at corresponding methane concentrations. Following flame extinguishment in upward propagation, the hot product gas region behind the flame front continued to rise in a predictable fashion as a coherent column into the nonflammable fuel-rich region. This hot column rose at a constant velocity, approximately equal to the flame speed at the time of flame extinguishment. Flame extinguishment limits in the layered mixtures were found not to be strongly dependent on tube diameter. Interferometric techniques developed in this study appear to be useful for the rapid measurements of flammability limits and flame propagation rates.

E. Suppression of Fires

Andreeva, T. A., Tyul'panov, R. S., Boldyrev, V. V., Bunev, V. A., Melamed, V. M., and Mitrofanova, R. P. (Novosibirsk, U.S.S.R.) "Study of the Effect of Some Dispersed Additives on the Propagation of Methane Flame," *Fizika Goreniya i Vzryva* **7**(1), 84–91 (March 1971) (in Russian)

Subjects: Methane flames; Additives; Propagation rate; Burning velocity; Inhibitors

Authors' Conclusions
Translated by L. Holtschlag

A study is made of the mechanism of the effect of various additives on burning in order to find new methods of controlling the burning processes of hydrocarbon systems as well as to determine the mechanism of the chemical processes developing in the flame. Considered was the effect of certain organic and inorganic dispersed materials on the normal propagation rate of a methane flame. The fuel was 98% natural methane. The additives were chemically pure, predried materials: Fe_2O_3, ground quartz, 2,4-diaminochlorohydrate and 3,3-dimethoxybenzidine. The experiments were carried out in a spherical steel reactor (160 mm dia.) with condensed spark ignition at room temperature and initial pressure of 1 atm. The normal flame spread was calculated from oscillograms of the variation of pressure in the reactor. The experiment and analysis show that even comparatively small additions of these materials (0.35 mg/1) can increase the flame velocity appreciably.

Buldovich, A. A. "Extinguishing Conical Spoil Heaps," *Ugol' Ukr* **16**(3), 44–45 (March 1972) (in Russian)

Subjects: Extinguishment of spoil heaps; Spoil heaps, extinguishment; Coal spoil fires

Safety in Mines Research Establishment Abstract, By Permission

Describes the extinction of conical spoil heaps by washing off with a hydro-monitor, re-shaping with a bulldozer, and filling with clay pulp. The advantages of this method compared with that using injection are given. 1 fig., 1 table.

Hoffman, W. (University of Karlsruhe, Karlsruhe, Germany) "Measuring the Efficacy of Dry Extinguishing Powders on a Laboratory Scale," *Ztschr. VFDB* **21**(1), 11–17 (February 1972) (in German)

Subjects: Extinguishment; Powders; Tests on dry agents

Safety in Mines Research Establishment Abstract, By Permission

Description and assessment of a laboratory test apparatus with which the amount of powder per unit of time required to extinguish a given test flame may be determined. An air—fuel mixture with high flame speed requires more powder than mixtures with a lower flame speed. The method can be used to determine influence of chemical composition, specific surface and particle size of a powder on the quenching efficacy. The tests were carried out at the Forschungstelle für Brandschutztechnik (Fire Protection Research Dept.), University of Karlsruhe. Discussion. 5 refs., 11 figs., 2 tables.

Kida, H. (Fire Research Institute of Japan, Tokyo, Japan) "Extinction of Fires of Small Wooden Crib with Sprays of Water and Some Solutions," *Report of the Fire Research Institute of Japan No. 36,* p. 6 (March 1973) (in Japanese)

Subjects: Extinction; Crib fires; Water; Sprays

Author's Abstract

The factors influencing the critical amount of water and some solutions required to extinguish small wooden crib fires were determined. Sprays of liquid were applied manually at a predetermined rate through a nozzle to each side of the burning crib. The required quantity of liquid was measured for various degrees of fire intensity obtained by varying the size of sticks, number of sticks per layer, and height of the crib. The effect of preburn time on the quantity of liquid was also examined.

Figures show (1) the relation between the preburn time of the model fire and the required amount of liquid and (2) the effect of application rate of the liquid on the amount of liquid required to extinguish the model fire is shown. It was found that the burning rate of the crib (V kg/min) and the weight of fuel lost (G kg) by the time when discharge of spray was started had a very important role on the amount of liquid required to extinguish the fire, Q (1). The measured value of Q is plotted against the value of G·V. The data obtained in this study were correlated by the following relations:

for water $Q = 0.90\ (G \cdot V)^{0.60}$

for diammonium phosphate 20 wt% solution

$$Q = 0.44\ (G \cdot V)^{0.60}$$

In this study, only limited data about the relation between the critical discharge rate to extinguish the model fire and the intensity of the fire were obtained. It is considered that, to determine this rate, not only V and G, but another factors, for instance V/W_0, where W_0 is the initial weight of the crib, must be taken into consideration.

Moriya, T. and Morikawa, T. (Fire Research Institute of Japan, Tokyo, Japan) "Fire Extinguishing Measures for Radioisotope Facilities: (2) Extinguishment of Liquid Fires in Enclosures by Dry Chemical Extinguishant," *Report of the Fire Research Institute of Japan No. 35,* pp. 31–32 (1972) (in Japanese)

Subjects: Radioisotope facilities; Extinguishants, dry; Liquid fires; Enclosures; Powder extinguishants

Authors' Abstract

The purpose of this study is to develop the methods of extinguishing fires in such artificially ventilated enclosures as hoods, glove boxes, and hot caves without allowing any contaminated materials to spread out of the enclosures.

In the previous report, a study in which carbon dioxide was used as extinguishant was presented.

For the present study, sodium bicarbonate based dry chemical extinguishant was used. Fire extinguishing experiments were conducted in two chambers each equipped with a ventilating system, one ($1.8\ m^3$) modeled after glove boxes or hoods, and the other ($29\ m^3$) after hot caves.

Experiments and results in the case of the chamber of $1.8\ m^3$

The dry chemical was discharged by means of compressed air from an air compressor linked with an extinguishant container toward the facing wall from a two aperture nozzle with its head 20 degrees upward, mounted just above the bottom by a wall, as it was made sure that this nozzle location was good enough to extinguish fires of any position after preliminary tests were made using the varying number of nozzles installed at various positions. The burning of hexane in a round tray of 20 cm dia located 70 cm above the nozzle was used as a fire model. The dry chemical application rate was measured by weighing the extinguishant container with dry chemical in.

The dry chemical was found to be applicable to fires in glove boxes, but not to be preferable for those in Oak Ridge type hoods with the sliding doors open. In the case of the latter, the dry chemical discharge could force the air in the hoods out through their windows and give rise to radioactive contamination outside the hood.

The extinction time increased with increasing the rate of ventilation but decreased with increasing the rate of application.

When it is assumed that the distribution of the dry chemical concentration is always even in the chamber, the relation between q, Q and t_E can be given by

$$t_E = \frac{V}{Q} \ln \frac{q}{q - C_E Q} \tag{1}$$

where V is the volume of chamber, Q the rate of ventilation, q the rate of application, C_E the extinction concentration and t_E the extinction time.

It was found in the experiments that 70 percent of the dry chemical discharged behaved together with air.

The extinction concentration C_E of 0.30 kg/m^3 was obtained from the experimental results and from Eq. 1 in which $0.7q$ substituted for q. Then the amount of dry chemical W required for extinguishment per cubic meter is given by

$$W = \frac{q t_E}{V} = \frac{q}{Q} \ln \frac{0.7q}{0.7q - 0.3Q} \qquad (2)'$$

The amounts W obtained from the experiments do not agree so well with those from Eq. (2)′, but both have somewhat similar patterns. According to these results, more than 0.5 of q/Q is desirable for the complete and economical extinguishment. In this case, the amount of dry chemical required is about 1.0 kg/m^3.

Experiments and results in the case of the chamber of 29 m³

Installation of four nozzles, each of which was installed at every upper corner pointing toward its symmetrical corner, was adopted in the experiments because it could cover the whole space in the chamber. The burning of hexane mostly in a 64 cm dia tray placed on the bottom of the chamber was used as the fire model.

The extinction time was little affected by the ventilating rate, so long as it was less than 180 times the volume of the chamber per hour. The amount of the dry chemical per cubic meter required for extinguishment was much smaller against fires in this chamber than against those in smaller one. The desirable rate of dry chemical application was obtained as 1.5 —40 $\times$ 10^{-2}kg/m^3/sec and the amount of dry chemical required as 0.25 kg/m^3 at most. The value

0.25 kg/m^3 is even smaller than 0.4 kg/m^3, the smallest value in the case of the chamber of 1.8 m^3.

The difference seemed due to the fact that fuel was burned on the bottom in the experiments in a larger chamber against far above the bottom in those in a smaller one, that the number of nozzles used was four in the former against one in the latter, and that the oxygen concentration was observed reduced during the former experiments because of the relatively large area of burning and lower ventilating rate.

Lack of oxygen would occur in most fires in hot caves in the light of the fact that in the experiments conducted in the larger chamber of the burning area of only 3.3% of the bottom area was quite small but led to reduction of oxygen concentration.

Nakakuki, A. and Takahashi, M. (Fire Research Institute of Japan, Tokyo, Japan) "Extinction of Fires with Water Sprays in Compressed and Oxygen-Enriched Atmospheres," *Report of the Fire Research Institute of Japan No. 35*, p. 23 (March 1972) (in Japanese)

Subjects: Water sprays; Sprays; Oxygen-rich atmospheres; Hyperbaric fire extinction; Extinction by water sprays

Authors' Abstract

Tests of extinction of fires of solid combustibles and a liquid fuel with water sprays in compressed and oxygen-enriched atmospheres were carried out. The difficulty of extinction increased far more with oxygen concentration than with total pressure, at the same partial pressure of oxygen. Liquid fires were greatly intensified by the entrained gas in the spray. The appropriate water spray properties for the solid combustible fire are (1) the large drop diameter, (2) the small velocity or the homogeneous velocity distribution of the entrained gas, and (3) the small contraction in the downward stream in compressed atmospheres.

Yamashika, S. (Fire Research Institute of Japan, Tokyo, Japan) "Studies on the Required Quantity of Various Fire Extinguishing Agents: Part 6. Results of the Critical Concentration for Flame Extinguishment by a New Method," *Report of the Fire Research Institute of Japan No. 36*, p. 12 (March 1973) (in Japanese)

Subjects: Extinguishing agents; Extinguishment; Test methods

A method of measuring a critical concentration of extinguishing agents required for flame extinguishment in laboratory is described in this report. The method is a static one, and can be used for fires of the gas, liquid, and solid fuel. The result by this method was compared with that by Creitz's one. An effect of oxygen concentration of surrounding air on the critical concentration was investigated.

The vessel used is shown. Its volume was 73.3 liters. Air is permitted to enter into the vessel from the floor, if necessary, and to flow out from the top. After introducing a definite volume of extinguishing agent, the fuel is ignited, and allowed to burn freely till it is extinguished by the mixing of increasing combustion products. The gaseous products in the vessel were analyzed by gas-chromatography. In Fig. 2, the starting gas concentrations are indicated by symbol x, and the gas concentrations at extinguishment are shown by various symbols for different fuels. The concentration for flame extinguishment in normal air can be found out on this graph as the concentration of extinguishing agent at the intersection of the line of the starting gas concentration and that of the extinguishing concentration.

The concentration for flame extinguishment was about two-thirds of the inerting concentration in explosion method. The reason may be attributed to the difference of diffusion flame and premixed flame, i.e., to the decrease of oxygen concentration as going into flame zone of diffusion flame.

The critical concentrations of various extinguishing agents for flame extinguishment of various fuels measured by the method modified partially are shown.

F. Fires, Damage and Salvage

Heselden, A. J. M. (Joint Fire Research Organization, Borehamwood, Herts., England) "Fire Problems of Pedestrian Precincts: Part 1. The Smoke Production of Various Materials," *Fire Research Note No. 856,* Joint Fire Research Organization (April 1971)

Subjects: Smoke, Shopping mall; Visibility; Smoke test; Fire propagation test; Pedestrian precincts

Author's Summary

The experimental full-scale section of a pedestrian shopping mall at the Fire Research Station is described and results given of the first test series, designed to measure the smoke production in vision-obscuring terms of a number of materials burnt under well-ventilated large fire conditions. The amount of smoke produced is given as D_s, the optical density per metre produced by burning 1 gram of the material in a stirred volume of 1 cubic metre, and D_s can be used

to obtain the visibility in other situations. Remarkably little of any of the fuels needs to be burnt to produce low visibilities in an enclosed, though large, volume. The worst materials gave an optical density per gram 7-9 times that of the best material. For wood and polyurethane agreement with data from small-scale tests is reasonably satisfactory, but for polystyrene much more smoke was produced than in a test employing the fire propagation test apparatus, possibly because of a different mode of combustion.

G. Combustion Engineering and Tests

Babkin, V. S. and V'ynn, A. V. (Novosibirsk, U.S.S.R.) "Mechanism of Laminar Flame Propagation at High Pressure," *Fizika Goreniya i Vzryva* **7**(2), 241–245 (June 1971) See **Section D.**

Blazowski, W. S., Cole, R. B., and McAlevy, R. F., III (Stevens Institute of Technology, Hoboken, New Jersey) "Linear Pyrolysis of Various Polymers under Combustion Conditions, *Fourteenth Symposium on Combustion*, p. 1177, the Combustion Institute, Pittsburgh, Pennsylvania (1973)

Subjects: Polymers, pyrolysis of; Pyrolysis of polymers; Kinetics of pyrolysis

Authors' Abstract

To characterize the kinetics of the linear pyrolysis of polymers under combustion conditions, impinging-jet diffusion-flame experiments were conducted on seven different polymers (linear and crosslinked polymethylmethacrylate, polyethylene, polypropylene, Delrin, Nylon 6–6, polyurethane). Surface brightness temperatures, typically of 500° to 600°C, were determined by infrared spectraradiometry, and were correlated with linear-pyrolysis rates, typically 0.08 to 0.4 mm/sec, using Arrhenius expressions. The observed apparent activation energies for linear pyrolysis could, in some cases (polypropylene, Delrin, Nylon 6–6, polyurethane), be correlated with bulk-pyrolysis data from the same polymers. In other cases (linear and crosslinked polymethylmethacrylate, polyethylene), further experimental testing and analytic modeling appear necessary before rational correlations can be made.

Bouck, L. S. (Cities Service Oil Company, Tulsa, Oklahoma), **Baer, A. D. and Ryan, N. W.** (University of Utah, Salt Lake City, Utah) "Pyrolysis and Oxidation of Polymers at High Heating Rates," *Fourteenth Symposium on Combustion*, p. 1165, the Combustion Institute, Pittsburgh, Pennsylvania (1973).

Subjects: Pyrolysis of polymers; Polymers, pyrolysis of

Authors' Abstract

A high-heating-rate, thermoanalytical technique was developed and applied in an investigation of the pyrolysis and oxidation of nine polymeric fuel binders typical of those used in composite propellants. The experimental method permitted detection and measurement of energy effects from reactions in samples heated nearly uniformly at rates from 50° to 300°K/sec. Tests were performed at pressures from 0.02 to 6.85 atm. The results of the high-heating-rate pyrolysis tests in a neutral atmosphere were different from those obtained by conventional laboratory techniques at low heating rates. Although in either case the energy effects were small compared to oxidation effects, a change in the pyrolysis mechanism with heating rate was apparent. Tests in which the polymers were oxidized either with gaseous oxygen or by the decomposition products of admixed ammonium perchlorate showed evidence of an exothermic reaction at a temperature 100° to 150°K below the sample ignition temperature. Although significant heating resulted from this reaction, it apparently became reactant limited and may be an essential precursor to the strongly exothermic runaway ignition reaction.

Boult, M. A. and Napier, D. H. (Safety in Mines Research Establishment, Sheffield, England) "Behaviour of Polyurethane Foams under Controlled Heating," *Fire Prevention Science and Technology* **3,** 13–18 (November 1972)

Subjects: Polyurethane; Foams; Pyrolysis; Fire retardants; Polymers; Toxic products

Safety in Mines Research Establishment
Abstract, by Permission

Listing the properties of flexible and rigid foams and fire retardants, the authors describe heat penetration tests and give the values of thermal diffusivity of polyurethane foam and describe weight loss and surface ignition effects and the evolution of phosphoric compounds during thermal degradation. Other factors described are the toxic products, the heating effects with oil contamination, and the smoke and gases produced by burning flexible polyurethane foam. 15 refs., 1 fig., 6 tables.

Bowes, P. C. (Fire Research Station, Boreham Wood, Herts., England) "Thermal Ignition in Two-Component Systems: Part II. Experimental Study," *Combustion and Flame* **19,** 55–68 (1972)

Subjects: Thermal ignition; Ignition; Two phase; Heterogeneous ignition; Critical site; Spontaneous ignition

Author's Abstract

A theoretical model for thermal ignition of a mixture of two components generating heat independently (Part I) is applied to the ignition of mixtures of wood sawdust and vegetable oil. It is shown that: (1) the ignition criterion of the model, which involves a nonarbitrary critical temperature increase, has a high degree of physical reality; (2) the model is, in principle, capable of predicting ignition from primary kinetic and thermal data; (3) it is likely to be possible often to make a reliable prediction of critical size for self-ignition in a two-component system at ordinary atmospheric temperatures by a simple extrapolation from small-scale ignition data, obtained at higher temperatures, in the same way as for ignition due to a single reaction.

Curcic, A. and Vukanovic, B. "Results of Dust Explosibility Tests on Coal from Yugoslavian Coal Mines," *International Symposium on Dust Explosion Risks in Mines and Industry*, Karlovy Vary, Czechoslovakia (October 11–13, 1972) (in German) See **Section B.**

Krishnamurthy, L. and Williams, F. A. (University of California at San Diego and La Jolla, California) "Laminar Combustion of Polymethylmethacrylate in O_2/N_2 Mixtures," *Fourteenth Symposium on Combustion*, p. 1151, the Combustion Institute, Pittsburgh, Pennsylvania (1973)

Subjects: Combustion of polymethylmethacrylate; Methylmethacrylate polymer, combustion of; Laminar combustion of polymethylmethacrylate

Authors' Abstract

The results of experiments on the combustion of polymethylmethacrylate (PMMA, Plexiglas) slabs in laminar flows of O_2/N_2 mixtures are reported. The Reynolds Number, based on streamwise distance from the leading edge of the slab, ranged from 1.5×10^3 to 6×10^4, the pressure from atmospheric to 1/15 atm, and the mol fraction of oxygen from 0.2 to unity. Measurements were made of surface regression rates, of flame standoff distances, of temperatures of the regressing surface, and of conditions for flame extinction. Regression rates agree reasonably well with theoretical results obtained from the flame-surface approximation for the boundary layer on a semi-infinite flat plate. Standoff distances agree with the same type of model, if account is taken of the axial pressure

gradient in the test section under hot-flow conditions, and of the reduction in flame temperature produced by dissociation and by radiative heat loss from the flame. The observed relationship between regression rate and surface temperature differs from that obtained earlier in hot-plate linear-pyrolysis experiments, and agrees with theoretical results that employ measured bulk degradation kinetics to calculate surface pyrolysis rates. Since these earlier calculations, based on the assumption of end initiation and unzipping, were believed to be accurate only for a degree of polymerization (DP) less than 2×10^3, and since the DP of our PMMA samples was 1 to 6×10^4, it appears that the earlier model may remain a useful approximation for a higher DP than expected. Observed extinction conditions are discussed in the light of some recent developments in extinction theory. Under the assumption that the gas-phase combustion process which occurs in the vicinity of extinction has an over-all order of 2, an extinction criterion is defined in terms of a critical value for the ratio of the square of the test-section pressure to the free-stream oxidizer mass flux. This critical value is influenced by the mol fraction of oxygen primarily through its dependence on flame temperature. The experimental results are consistent with an activation energy of roughly 20 kcal/mol, and a preexponential factor of the order of 10^{14} cm^3/mol sec for the over-all combustion of gaseous PMMA degradation products with O_2 in a diffusion flame near the extinction limit.

Kanury, A. Murty (Stanford Research Institute, Menlo Park, California) "Rate of Charring Combustion in a Fire," *Fourteenth Symposium on Combustion,* p. 1131, the Combustion Institute, Pittsburgh, Pennsylvania (1973)

Subjects: Charring combustion; Pyrolysis of wood; Wood charring

Author's Abstract

This paper deals with the rate and extent of charring of solid fuels, to forecast the intensity of a fire and the integrity of a structure. Literature review shows that most of the existing knowledge on wood charring is of empirical nature, and all the available theoretical work assumes Arrhenius-type pyrolysis kinetics, which invariably lead to numerical solutions. Hypothesizing that wood-pyrolysis kinetics, under realistic fire conditions, may be characterized by a "pyrolysis temperature," at the attainment of which the solid pyrolyzes profusely, and a "char temperature," at the attainment of which the solid is completely converted to char, this paper shows that the pyrolysis wave thickness is directly proportional to: (1) the solid thermal conductivity and (2) the temperature range in which the pyrolysis rate is measurable; and is inversely proportional to (3) the exposure heat flux and (4) the uncharred depth fraction. Neglecting the property variations, reactions in the char, moisture migration, internal convection, and fissure formation, the energy equation is solved with the assumption that the preheat temperature profile in the virgin zone is not significantly affected by the presence of the pyrolysis wave. The predicted trends are in excellent agreement

with the available experimental data. Of special interest is the prediction that the pyrolysate mass flux at the surface is independent of the specimen thickness for thin solids, and is inversely proportional to the thickness for thick solids. By a passive technique suggested by the present analysis, data on the time to burn through 0.5-in.-thick planks of assorted species of wood are used to estimate the pyrolysis endothermicity to be 73–100 cal/g of volatiles. For α-cellulose and pine wood, it is determined respectively to be 73 and 78 cal/g volatiles. An expression for Spalding's mass-transfer number B is obtained, incorporation of which in the stagnant-film hypothesis is shown to adequately describe the fire/fuel interaction, wherein the pyrolysis and boundary-layer phenomena adjust one another to bring about a stable combustion situation.

Khomyak, E. and Yarosinskii, Yu. (Warsaw, Poland) "Application of Ionized Current Measurements to the Determination of Turbulent Flame Structure," *Fizika Goreniya i Vzryva* **6**(3), 390–400 (September 1970)

Subjects: Turbulent flame structure; Ion current in turbulent flames

Authors' Conclusions
Translated by L. Holtschlag

A pickup for local measurement of the ionization current in a turbulent flame is described. The pickup signal is linearly dependent on the concentration at the edge of the boundary layer of the measurement element of the pickup. Magnitude of the signal depends on the rate of gas flow and on the temperature of the sensor. The ionization signal in a homogeneous laminar flame varies in the limits ±30%. The size of the space in which increased ionization occurs is several times greater than the thickness of the laminar burning front. In the turbulent flame zone, the signal varies within broad limits; intermediate signal values appear frequently. The maximum signal amplitude in turbulent flame is substantially greater than the corresponding values in a laminar flame. The turbulent flame contains pockets in which an expanded homogeneous ionization signal was found. In the depth of the turbulent flame zone, the ionization current signal is continuous; its value does not drop to zero and resembles recording of a random process. Accelerations acting on the flame front affect the ionization structure. All these factors indicate that the method used here is qualitative for the case of real turbulent flames. The method is suitable for study of the flame front in a steady-state flow, when the sensor does not heat up and the pressure pulsations are small.

Liebman, I., Corry, J., and Perlee, H. E. (Safety Research Center, Bureau of Mines, U. S. Department of the Interior, Pittsburgh, Pennsylvania) "Dynamics of Flame Propagation through Layered Methane—Air Mixtures," *Combustion Science and Technology* **2**, 365–375 (1971) See **Section D.**

Moriya, T., Shimada, H., and Morikawa, T. (Fire Research Institute of Japan, Tokyo, Japan) "Heat Transfer Coefficient from Fire in a Reinforced Concrete Building," *Report of Fire Research Institute of Japan No. 35,* p. 39 (March 1972)

Subjects: Heat transfer coefficients; Buildings; Reinforced concrete; Concrete buildings

Authors' Abstract

The purpose of this study is to give an idea about the heat transfer coefficient in cases where a metallic block is heated by fire in a reinforced concrete building.

The room used for a fire experiment was 3.3 m high and of a floor area of 242 m^2. There were fire-woods of 12 tons or 50 kg per m^2 evenly distributed on the floor but not any combustible materials on the walls or ceiling of the room. A cylindrical iron specimen with 10 cm diameter and 20 cm height was mounted 1.5 m above the floor in the middle of the room. The temperatures of the iron specimen and the surrounding atmosphere were measured continuously by C-A thermocouples during the fire experiment.

The total heat transfer coefficients at intervals of 5 minutes during the period of fire were obtained from the results of the temperatures measured and the equation (2).

The fire temperature in the most violent period of fire can be regarded as 850°C constant. The total heat transfer coefficients at intervals of 1 minutes as regards 850°C fire were obtained also from equation (2).

The emissivity of the atmosphere in a reinforced concrete building in the case of the fire in its violence was obtained by calculation in which the heat transfer coefficients above mentioned were used.

It was found that the total heat transfer coefficient in the case of the fire temperature θ_f of 850°C were approximately 90, 115, 130 Kcal/m^2 h°C against 400, 530, 650°C of the surface temperature of the iron specimen, respectively.

The product of the emissivity and the shape factor of the fire in its violence (850°C of fire temperature) is presumed to be 0.6.

Raftery, M. M. "Ignition Properties of Dust/Air Mixtures—the Development of Explosibility Tests," *International Symposium on Dust Explosion Risks in Mines and Industry,* Karlovy Vary, Czechoslovakia (October 11–13, 1972) See **Section B.**

Roberts, A. F. and Quince, B. W. (Safety in Mines Research Establishment, Department of Trade and Industry, Buxton, Derbyshire, England) "A Limiting Condition for the Burning of Flammable Liquids," *Combustion and Flame* **20,** 245–251 (1973)

Subjects: Liquids, flammable; Flammability; Fire point; Diffusion burning; Limits of flammability; Theory of flammability

Authors' Abstract

The *fire point* is the lowest temperature of a liquid surface at which sustained *diffusional burning* of the liquid can occur. An explanation of the fire point has been developed in which the theoretical temperature of a flame burning above a liquid surface is related to the temperature of the surface; it is then assumed that the borderline between extinction and sustained burning occurs at some critical value of the theoretical flame temperature, due to the influence of reaction kinetics. This explanation was tested by determining the fire points of seven pure liquids. The derived values of the theoretical flame temperature were in the range 1530–1710°K, which may be compared with a limiting temperature of about 1600°K for the sustained burning of gaseous hydrocarbons in atmospheres progressively diluted with nitrogen. It is therefore concluded that the explanation offered for the phenomenon is a reasonable one.

Scott, K. A. (Safety in Mines Research Establishment, Sheffield, England) "Plastics in Fire. Currently Accepted Materials and Future Trends," *Paper No. 4—Conference on Plastics in Fire,* I. E. E., London, England (November 1971) (25 pages)

Subjects: Polymers; Flammability; Tests

Safety in Mines Research Establishment
Abstract, by Permission

The author comments on the classification of materials by the spread of flame test, summarises the accepted plastics applications in buildings and considers future definitions of Class-O and others based on the fire propagation test. He indicates ways in which the hazards presented by smoke and toxic products may be minimised. 7 tables.

Seigel, L. G. (Applied Research Laboratory, United States Steel Corporation, Monroeville, Pennsylvania) "Designing for Fire Safety with Exposed Structural Steel," *Fire Technology* **6,** 269 (1970)

Subjects: Liquid-filled structural steel; Flame impingement shields; Structural steel, exposed

Author's Conclusions and References

Conclusions

The principles of structural fire protection described in this paper may be useful to architects and engineers who wish to design buildings with exposed steel structural members. A system of protection may be designed for any type of fire exposure by making use of liquid-filled members or flame-impingement shields. However, since the type of fire exposure that may develop is often dependent upon the geometry and architectural features of a building, the fire protection problem should be considered early when concept designs are being developed.

References

1. Seigel, L. G. "Water-Filled Tubular Steel Columns—Fire Protection without Coating," *Civil Engineering* (September 1967).
2. Wright, G. F. U.S. Patent 307,249 (October 28, 1884).
3. Pomeroy, F. E. U.S. Patent 583,293 (May 25, 1897).
4. Multin, P. U.S. Patent 3,050,134 (August 21, 1962).
5. "If Fire Strikes These Buildings, Convection Will Save the Frames," *Engineering News Record* (January 8, 1970).
6. Seigel, L. G. "Design of Liquid-Filled Structural Members for Fire Resistance," *Acier-Stahl-Steel* (June 1969).
7. Ehm, H. and Bongard, W. "Feuerwiderstandsfähigkeit von Wassergekühlten Stahlstützen," *Der Stahlbau* (June 1968).
8. McDonald, J. L. U.S. Patent 2,809,074 (October 8, 1957).
9. Seigel, L. G. "The Projection of Flames from Burning Buildings," *Fire Technology* **5**(1), 43–51 (February 1969).
10. Seigel, L. G. "Fire Test of an Exterior Exposed Steel Spandrel Girder," *Materials Research and Standards* (February 1970).

Shtessel, E. A., Pribytkova, K. V., and Merzhanov, A. G. (Moscow, U.S.S.R.) "Numerical Solution of the Thermal Explosion Problem Taking into Account Free Convection," *Fizika Goreniya i Vzryva* **7**(2), 167–178 (June 1971)

Subjects: Explosions, theory of; Convection; Thermal explosions; Gravity effects on thermal explosions

Authors' Conclusions
Translated by L. Holtschlag

An attempt at numerical solution of the equations of thermal explosion simultaneously with the equations of motion of a fluid in a gravity field is made. The study applies to a closed region of square cross section, infinite in one of the horizontal directions and filled with a chemically reacting fluid. All the properties of the fluid in this direction are considered constant, i.e., the dependence of the desired variables on only two coordinates will be considered. The temperature of the horizontal boundaries is constant; the vertical boundaries are thermally insulated. Four characteristic regions are found to exist: I—stationary reaction in a fixed fluid (thermal explosion and convection do not occur); II—stationary reaction in a moving fluid (thermal explosion absent; convection occurs); III—nonstationary reaction (thermal explosion) in a moving fluid; convection affects the induction period of the thermal explosion; IV—nonstationary reaction in a fixed fluid; convection does not develop during the induction period of the thermal explosion. Two conditions must be fulfilled for convection to affect the nature of the thermal explosion: the necessary condition of occurrence of convection in a chemically reacting fluid ($Ra \geq Ra$); the sufficient condition of development of convection (the induction period of convection less than or equal to the induction period of thermal explosion).

Strehlow, R. A. (Department of Aeronautical and Astronautical Engineering, University of Illinois at Urbana-Champaign, Illinois) "Unconfined Vapor-Cloud Explosions—An Overview," *Fourteenth Symposium on Combustion*, p. 1189, the Combustion Institute, Pittsburgh, Pennsylvania (1973)

Subjects: Vapor-cloud explosions; Explosions; Spills, explosion of; Flame buoyancy; Review on vapor explosions

Author's Abstract

The explosion of unconfined vapor clouds produced by the dispersion of flammable liquid or vapor spills is becoming a serious problem, mainly because of the increased size of the spills in recent years. This paper surveys accidental explosions that have occurred over the past 40 years and also evaluates recent research efforts which pertain to the dispersion and explosion of large vapor clouds. The major problem appears to be the lack of a fundamental understanding of a transient flame-buoyancy interaction during combustion of the cloud, since both accidental and deliberate explosions have exhibited over-all flame propagation rates almost an order of magnitude above the values one would expect without the consideration of buoyancy effects. Other problems which are discussed include (1) the initial dispersion of the cloud, (2) the prediction of blast effects, and (3) the question of direct initiation of detonation. Recommendations for future research are given.

Thomas, P. H. (Joint Fire Research Organization, Borehamwood, Herts., England) "Self-Heating and Thermal Ignition—A Guide to Its Theory and Application," *Ignition, Heat Release, and Non-combustibility of Materials, ASTM STP 502*, pp. 56–82, American Society for Testing and Materials (1972) See **Section B.**

Wilson, A. G. and Shorter, G. W. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "Fire and High Buildings," *Fire Technology* **6,** 292 (1970)

Subjects: High-rise buildings; Smoke control; Fire in high-rise buildings

Authors' Remarks and References

Remarks

The time necessary to evacuate today's high-rise buildings in a fire emergency is unsatisfactory from the standpoint of the development of untenable smoke conditions. The Division of Building Research has been working on the problem for several years and suggests several approaches to controlling smoke movement in buildings.

Design of smoke control systems, particularly those employing air supply or exhaust and vented shafts, requires knowledge of building leakage characteristics and careful analysis of the effects of these measures on building pressures and airflows. Measures selected may, for example, produce high-pressure differences across exits requiring special door arrangements. Requirements for residential and other buildings with sleeping occupants may be more rigorous than those for other occupancies. The optimum approach will depend on the nature of the building and its use, on climate, and on fire safety objectives.

It cannot be overemphasized in considering fire and high buildings that many fields of competence must become involved if effective and economic fire protection measures are to be developed. For example, if smoke control systems that utilize air-handling systems are to be incorporated in a building design, a mechanical engineer normally responsible for the day-to-day environmental conditions in buildings should play a prominent role. This approach, which has been described in recent years as the "systems" approach, must be exploited by fire protection engineers if truly comprehensive designs for the fire safety of high buildings are to be provided.

References

1. Hutcheon, N. B. "The Challenge of Tall Buildings Research and Regulations," a paper presented at the Annual Meeting of the Association of Canadian Fire Marshals and Fire Commissioners (June 23–27, 1969).
2. Galbreath, M. "Time of Evacuation by Stairs in High Buildings," *Fire Fighting in Canada* (February 1969).
3. Tamura, G. T. "Computer Analysis of Smoke Movement in Tall Buildings," a paper presented at the Annual Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (June 1969).
4. McGuire, J. H., Tamura, G. T. and Wilson, A. G. "Factors in Controlling Smoke in High Buildings," a paper presented at the American Society of Heating, Refrigerating, and Air-Conditioning Symposium *Fire Hazards in Buildings*, San Francisco, California (January 1970).
5. Tamura, G. T. and Wilson, A. G. "Pressure Differences for a Nine-Storey Building as a Result of Chimney Effect and Ventilation System Operation," *ASHRAE Transactions* **72**(1), 189–189 (1966).

6. Tamura, G. T. and Wilson, A. G. "Pressure Differences Caused by Chimney Effect in Three High Buildings" and "Building Pressures Caused by Chimney Action and Mechanical Ventilation," *ASHRAE Transactions* **73**(11) (1966).
7. McGuire, J. H. "Smoke Movement in Buildings," *Fire Technology* **3**(3), 163–174 (August 1967).
8. Tamura, G. T. "Analysis of Smoke Shafts for Control of Smoke Movement in Buildings," a paper presented at the Annual Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (June 1970).
9. Tamura, G. T. and Wilson, A. G. "Natural Venting to Control Smoke Movement in Buildings via Vertical Shafts," a paper presented at the Annual Meeting of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (June 1970).
10. Tamura, G. T., McGuire, J. H., and Wilson, A. G. "Air-Handling Systems for Control of Smoke Movement," a paper presented at the American Society of Heating, Refrigerating, and Air-Conditioning Symposium *Fire Hazards in Buildings,* San Francisco, California (January 1970).

Yamashita, K. and Inagaki, M. (Fire Research Institute of Japan, Tokyo, Japan) "Study of the Merger of Fires," *Report of Fire Research Institute of Japan No. 34,* p. 20 (September 1971) (in Japanese)

Subjects: Fires, merging of; Merging of fires

Authors' Abstract

The purpose of this study is to investigate the phenomena of the merger of fires and to help to estimate the damage by multiple fires when great earthquakes occur.

It was clarified by this study that the merger of fires was greatly influenced by the kind of fuels. At multiple gasoline fires, strong interaction effects of fires were observed and both flame height and burning rate increased rapidly at the merged fire, especially in the central part of fires. While, at multiple crib fires, weak interaction effects of fires were observed and neither flame height nor burning rate increased so much.

It is, moreover, suggested that the merged fire will occur when dimensions separation distance between fires ($g_n = S/L$) is smaller than a given value (g_o) and this criterion means that merged fire will easily occur under the condition that separation distance between fires is small and flame height is large.

In rare occasions, fire whirls were observed in the series of experiment of multiple fire at the central or leeward part of multiple fires under weak wind.

Yao, C. and Kalelkar, A. S. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Effect of Drop Size on Sprinkler Performance," *Fire Technology* **6,** 254 (1970) See **Section I.**

H. Chemical Aspects of Fires

Andreeva, T. A., Tyul'panov, R. S., Boldyrev, V. V., Bunev, V. A., Melamed, V. M., and Mitrofanova, R. P. (Novosibirsk, U.S.S.R.) "Study of the Effect of Some Dispersed Additives on the Propagation of Methane Flame," *Fizika Goreniya i Vzryva* **7**(1), 84–91 (March 1971) (in Russian) See **Section E.**

Boult, M. A. and Napier, D. H. (Safety in Mines Research Establishment, Sheffield, England) "Behaviour of Polyurethane Foams under Controlled Heating," *Fire Prevention Science and Technology* **3,** 13–18 (November 1972) See **Section G.**

Broido, A. and Weinstein, M. (Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Berkeley, California) "Low-Temperature Isothermal Pyrolysis of Cellulose," *Thermal Analysis* **3,** 285, Proceedings of the Third I.C.T.A., Davos, Switzerland (1971)

Subjects: Thermogravimetry; Pyrolysis; Cellulose

Authors' Abstract

By providing continuous weight measurement, thermogravimetry, even for isothermal experiments, offers a major advantage over the classical methods of determining weight-change curves in complex pyrolysis reactions. Thus, even minor weight changes, readily detectable on a continuous record, furnish clues concerning the reaction sequences and indicate conditions under which confirmatory experiments may be undertaken. Unfortunately, such perturbations are frequently ignored, being considered part of the "experimental error" which they often represent in the traditional experiments. This paper illustrates the utility of looking at the minor weight deviations, too large to be random experimental error, in a 1,000-hour isothermal pyrolysis experiment on high purity cellulose paper at 226°C. Resolution of the curve into the minimum number of consecutive and competing reactions required to fit within instrumental accuracy, yields previously unrecognized characteristics of the pyrolysis behavior, applicable at other temperatures as well.

Hoshino, M. and Fujieda, T. (Fire Research Institute of Japan, Tokyo, Japan) "Studies on Factors Influencing the Deterioration of Fire-Fighting Foam Compounds: IV. The Influences of Oxygen and Nitrogen on the Deterioration of

Foam Compounds," *Report of Fire Research Institute of Japan No. 34,* p. 44 (September 1971) (in Japanese)

Subjects: Foam deterioration; Fire-fighting foam compounds

Authors' Abstract

Concerning the deterioration of hydrolyzed protein (Keratin)-base foam compounds hydrolyzed with natrium hydroxide, it was necessary to investigate the influence of oxygen or nitrogen on the foam compounds to which ferrous salts such as $FeSO_4 \cdot 7H_2O$ or $FeCL_2 \cdot 4H_2O$ have been added.

The experimental procedure used for this investigation was as follows:

(A) The measurement of *p*H value, precipitation, foaming height determined by Ross and Miles method and dissolved oxygen concentration of the foam compounds were carried out, when oxygen gas was passed through the nonferrous foam compounds and the iron-containing foam compounds to which $FeSO_4 \cdot 7H_2O$ was added in varying amounts.

The foam compounds used in the experiment were prepared by Prof. Iino's Laboratory of the Faculty of Engineering, Tokyo Agricultural and Technical College, (Koganeishi/Tokyo) in cooperation with the authors' laboratory. The dissolved oxygen concentration was measured with a Beckman's oxygen-analyzer.

(B) Each sample (100 ml) of foam compounds containing varying amounts of $FeSO_4 \cdot 7H_2O$ was stored in a 300 ml flask (glass) in which gaseous oxygen or nitrogen or air was sealed.

The flasks were heated at 60°C for 24 hours, continuously cooled at −10°C for an additional 24 hours. The process of heating and cooling was repeated continuously 7 times (for 14 days).

After 14 days of the process, *p*H value and amount of precipitate of each sample in the flask were measured.

On the basis of the experimental results, it was proved that the deterioration of foam compounds containing ferrous salt was promoted by the existence of oxygen, but on the other hand, was inhibited by the existence of nitrogen. The cause of the deterioration could be explained by the formation of water-insoluble complexed compounds such as [hydrolyzed protein-Fe (II, III)-O_2] to which the water-soluble iron connected hydrolyzed protein such as [hydrolyzed protein-Fe (II, III)] have been changed by adsorption of oxygen from both the air and the foam compounds.

Mallinder, R. (Safety in Mines Research Establishment, Sheffield, England) "Phosphorus Compounds as Flame Retardants for Plastics," *Paper No. 12, Conference on Plastics in Fire,* I. E. E., London, England (November 1971) (13 pages)

Subjects: Flame retardants; Polyurethane foams; Polyesters; Halogen compounds

Author's Abstract

The incorporation of phosphorus compounds into polyurethane foams and polyesters in order to confer flame retardancy is briefly reviewed. The synergistic effects obtainable with halogen compounds are discussed. 7 refs., 3 tables.

Morikawa, T. (Fire Research Institute of Japan, Tokyo, Japan) "Spectrophotometric Analysis by Prussian Blue Method of HCN in the Burned Gas of Nitrogen-Containing Synthetic Polymers," *Report of Fire Research Institute of Japan No. 35*, pp. 17–18 (March 1972) (in Japanese)

Subjects: HCN; Analysis of HCN; Prussian blue; Polymers; Nitrogen-containing polymers

Author's Abstract

Poisoning by toxic gases has become a leading cause of fire deaths in recent years. Hydrogen cyanide (HCN) has been considered as one of the most dangerous toxic gases formed during the burning of polymers. Measuring of HCN, when it is contained in burned gases, is often disturbed by some unaimed gases, especially in the case of indirect measuring methods.

This paper deals with an experimental study in which amounts of HCN formed by the burning of various nitrogen-containing polymers were measured by means of a modified Hara and Matsumura's Prussian blue spectrophotometry (one of the direct methods).

Pyrolysis and combustion of various polymers and collection of HCN formed were carried out. Under the controlled condition of the air supply rate and the temperature of the air flowing, the combustion and pyrolysis of samples were carried out in a quartz tube (3.6 cm i.d.) in an electric furnace whose electric current was on-off controlled by a temperature controller linked with a thermocouple in the tube. A sample burned at one time was limited to a small amount, so that it could be heated fast. A part of sample contained or not in an aluminum or stainless steel boat was carried into the central part of the furnace by a spoon. When it finished burning, the next part was carried, and so on. HCN in the burned gas was collected in a series of five impingers containing KOH solution. The gas intake port of the impinging system was not closely connected with the quartz tube in order to prevent the pressure in the tube from getting lower.

Measurement of HCN absorbed in KOH solution was made after Prussian blue precipitate, which was formed by the process of the expressions (1), (2) and (3), was dissolved by addition of a small amount of oxalic acid solution. The dissolved Prussian blue solution was analyzed by an spectro-photometer at the wave length of 690 mμ.

HCN could be found present in the burned gases, when each sample material used in the present experiments was burned at 650°C.

The HCN yield from Nylon-6 burning, on the whole, increased with increasing temperature, while, in the case of flaming burning, it decreased with increasing air supply rate but reversed in the range of very small air supply. So long as the ratio of the air supply rate to the weight of sample burned through one time spoon operation was the same, the HCN yield took a certain value regardless of the weight of sample burned by one time spoon operation and the air supply rate. For other polymers, the trend of HCN yield is expected to be similar to that from nylon burning.

The results suggest that the HCN formation is only dependent on thermal decomposition temperature. In the case of large air supply rate, HCN once formed or released could be decomposed or burned through its oxidation by air. But oxygen in the air could contribute to the flame temperature rise which results in the larger yield of HCN. So the HCN yield is considered to have increased with the increase of air supply rate in the range of small air supply rate.

Since the rate of Prussian blue formation from CN^- was rather low in the range of low concentration of CN^-, the HCN analysis by Prussian blue spectrophotometry may not be termed as quite sensitive.

But it is advantageous in the case of analysis of HCN contained in the burned gas because no misleading reaction accompanied.

Tverdokhlebov, V. I. and Chirkin, N. N. (Dnepropetrovsk, U.S.S.R.) "Nature of the Excitation of Radicals in Hydrocarbon Flames," *Fizika Goreniya i Vzryva* **6**(4), 569–570 (December 1970) (in Russian)

Subjects: Hydrocarbon flames; Radicals; Excitation; Spectroscopy

Authors' Conclusions
Translated by L. Holtslag

In order to check the hypothesis that the excited C_2 radical can form in the process of recombination of a hydrocarbon ion with the electron, the radiation intensity of the Swan C_2 bands was measured with flame parameters constant and the concentration of ions and electrons varying within rather broad limits. Stoichiometric acetylene-air mixtures were burned on a flat-flame burner. The spectral radiation region of the flame was picked up by a monochromotor. The radiation receiver was a photomultiplier. The electrons and ions were removed from the flame by applying a longitudinal electric field. The results are given in a table, indicating that the formation of excited C_2 and CH radicals is not connected with the electron-ion recombination process.

Uehara, Y. (Fire Research Institute of Japan, Tokyo, Japan) "Electronic Structures of Some Halomethanes and an Interpretation of Their Inhibiting Effects by Simple LCAO Method," *Report of Fire Research Institute of Japan No. 35,* p. 12 (March 1972) (in Japanese)

Subjects: Halomethanes; LCAO; Electronic structure; Inhibition

Author's Abstract

Electronic structures of some halogenated methanes were calculated using simple LCAO MO method and discussed in connection with electron attachment theory. Calculated results are shown.

From the results, it was found that the lowest vacant orbitals of halomethanes were far lower than that of methane, and the bond orders of molecular ions became smaller than those of neutral molecules. The former means that the lower the lowest vacant orbital, the easier the electron attachment, i.e., a negative molecular ion forms easily, and the latter indicates that a negative halogen ion is formed readily from the molecular ion.

On the other hand, Mills' process can be divided into two steps: (1) an electron attaches to a molecule and easily forms a molecular ion, (2) C—X bond in it dissociates readily and a negative halogen atom ion is formed.

The above steps are interpreted in terms of LCAO treatment as follows: (1) the lowest vacant orbital is very low, (2) C—X bond strength in a molecular ion is weaker than that of neutral one. It is clear that these results obtained from the electron attachment theory agree with those from electronic structures of halomethanes.

Thus it is concluded that the study on electronic structures of halomethanes gives a substantial support to the electron attachment theory on inhibition. For example, it is shown that values of the lowest vacant orbitals of halomethanes and their inhibiting effects are closely correlated, except fluorine-containing compounds.

I. Physical Aspects of Fires

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Effect of Scattered Light to Measurement of Smoke Density," *Report of Fire Research Institute of Japan No. 34,* p. 37 (September 1971) (in Japanese)

Subjects: Smoke; Light scattering

Author's Abstract

Present paper deals with the effect of scattered light to measurement of smoke density in case of using smoke meter without lens. A hood is attached with

photoelectric element, CdS photo-conductive cell, instead of lens. White smoke is generated by a smoke bomb.

From the experimental results it appears that the smoke meter with the hood of diameter 2.7 cm and length 10 cm could be used within 1.5/m of extinction coefficient, and the meter with hood of diameter 1.3 cm was better than the former and could be used within 2.0∼2.5/m.

The obtained values can be corrected theoretically.

Nakata, K. and Yamashita, K. (Fire Research Institute of Japan, Tokyo, Japan) "Attenuation of Radiation through Water Spray," *Report of Fire Research Institute of Japan No. 34,* p. 31 (September 1971) (in Japanese)

Subjects: Radiation; Water spray; Sprays

Authors' Abstract

We have investigated the possibility of checking the heat and smoke from spreading along corridors by making use of air curtain and water curtain. The partial results of this study were reported previously. The problem of estimating the degree of attenuation of radiation through water spray has been investigated by some investigators, but the character of water spray has not been identified and their results are not directly applied to our purpose.

We took up this problem to clarify the mechanism of attenuation of radiation and also to estimate the quantity of water sufficient to diminish the radiation transmission through water curtain up to safe level.

At first, characteristics of water spray were investigated experimentally and, next, radiation transmissions through water curtain were measured under various spray conditions. A flame of n-hexane was used as radiation source. Water sprays were ejected from some spray nozzles, a sprinkler head, and a line water curtain head.

The transmission data were figured in terms of reduced virtual film thickness of water ($h = Qd/v$) and virtual absorption coefficient of water film was estimated to be about 30 1/cm in this experiment.

Nii, R. (Fire Research Institute of Japan, Tokyo, Japan) "Relationship between Mean Velocity of Inflow-Air into Medium Expansion Foam Generators and Foam Number of Generated Foam," *Report of Fire Research Institute of Japan No. 34,* p. 49 (September 1971) (in Japanese)

Subjects: Foam generators; Foam number

Author's Abstract

Supply rate of air volume required to generate air foam with a medium-expansion foam generator depends upon volume rate or mean velocity or inflow-air by which a fog stream of foaming solution discharged from a fog nozzle is accompanied into the generator.

Foam number of foam generated from the generator can be calculated from the following equation (1) which was newly introduced by the author with some modifications of theoretical expansion ratio, which was defined previously by the author for high-expansion foam.

$$E_M = \frac{w_f 60 S_o}{Q} = \frac{w_f}{Q/60S}\left(\frac{S_o}{S}\right) \qquad (1)$$

where E_M is foam number; w_f, mean velocity of inflow-air into a medium-expansion foam generator (cm/s); Q, discharge rate from a fog nozzle (l/min); S_o, cross section of air inlet of the generator (cm²); and S, used area of a net or a multihole-plate in case of foaming. Now, the following equation is introduced:

$$Z_M = Q/60S \qquad (2)$$

where Z_M (cm/s) means mean thickness of foaming solution supplied onto unit area of the net or the multihole-plate per unit time. Z_M has practically a value of 20 to 300 times as large as the optimum one for high-expansion foam, which is 0.07 cm/s, according to various discharge rates and used areas of net or multihole-plate. Substituting Eq. (2) into Eq. (1), Eq. (3) is obtained.

$$E_M = w_f S_o / Z_M S \qquad (3)$$

In the case, that only water is discharged from a fog nozzle in a medium-expansion foam generator and mean velocity of inflow-air into the generator is expressed with w (cm/s), Eq. (4) is obtained from some experimental results and consideration as follows:

$$w_f = (2 - Ak)w \qquad (4)$$

where A and k show an opening percentage of used net or multihole-plate and an effective coefficient of opening percentage, respectively. The values of A and k are usually 0.45 ± 0.05 and 0.95, respectively. Substituting Eq. (4) into Eq. (3), Eq. (5) is obtained as follows:

$$E_M = (2 - Ak)\ wS_o / Z_M S \qquad (5)$$

As a result of investigating the experimental data about the two Nohmi- and Tosho-type of practical medium-expansion foam generators, the validity of the equations as mentioned above was confirmed. But it is concluded, that with regard to velocity of inflow-air into a medium-expansion foam generator, further systematic investigations should be performed in correlation with constructions and sizes of fog nozzles used in the generator.

Yao, C. and Kalelkar, A. S. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Effect of Drop Size on Sprinkler Performance," *Fire Technology* **6,** 254 (1970)

Subjects: Sprinkler performance; Drop size

Authors' Conclusions

Based on investigations conducted thus far, the following conclusions can be made:

- Water drops discharged from sprinklers are expected to perform three functions effectively and efficiently—penetrate the fire plume to reach the burning fuel surfaces; cool the radially spreading hot gases under the ceiling; and wet the immediate surrounding combustibles.
- Water density distributions measured under no-fire conditions are quite different than with a fire in progress under the sprinkler.
- Theoretical and experimental results show that large drops can penetrate the fire plume at higher velocity and, therefore, are more effective for larger fires than the smaller drops. Optimum drop size for fire extinguishment is 4 mm to 5 mm in diameter.
- The fine drops (less than 0.5 mm) are more effective for cooling the surrounding atmosphere, especially under the ceiling, to prevent remote sprinklers from opening.
- At a normal operating pressure of 28 psi, the standard sprinkler produces drops with a mean diameter by weight of about 1 mm. About 8 percent by weight are larger than 2 mm, and about 4 percent by weight are smaller than 0.5 mm. It appears that the standard sprinkler was designed to convert the water discharge into a compromise size distribution, i.e., few large and small drops, but with a large quantity of intermediate size drops, which do not perform most of the useful functions cited.
- With a special large orifice sprinkler (1⁵⁄₁₆ in.) operating at a pressure of 2.5 psi, the mean drop size was found to be about 3.5 mm in diameter.

In order to provide an optimized drop-size distribution, a new dual nozzle sprinkler is being developed. It consists of a fog nozzle and a large orifice sprinkler. The new sprinkler is designed to project a fine spray of fog radially beneath the ceiling and a downward spray of large drops of high penetrative ability.

J. Meteorological Aspects of Fires

Reid, D. G. and Vines, R. G. (C.S.I.R.O., Melbourne, Australia) "A Radar Study of the Smoke Plume from a Forest Fire," *Division of Applied Chemistry Technical Paper No. 2,* Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia (1972)

Subjects: Forest fires; Smoke plumes; Plumes; Radar studies

Authors' Abstract

The development of the smoke cloud from a summer wildfire in a forest area was studied on a radar screen. In conjunction with photographs taken at the same time, it has been possible to follow the variations in height of both the top and bottom of the smoke column as it was blown downwind; estimates of the rate of rise of the smoke, at different heights, were also obtained.

The general behaviour of the smoke cloud is interpreted in terms of the prevailing winds, and the lapse rate in the surrounding air.

K. Physiological and Psychological Problems from Fires

Griffin, O. G. and Atherton, E. (Safety in Mines Research Establishment, Department of Trade and Industry, Sheffield, England) "The Physiological Requirements for Self-Rescuers Related to the Performance of Existing Apparatus," *American Occupational Hygiene* **15,** 361–375 (1972)

Subjects: Respirators; Self-rescuers; Physiological requirements

Authors' Abstract

Carbon monoxide poisoning is one of the most common causes of death in mine fires and explosions. Self-rescuers, which are designed to provide protection against this hazard, are respirators which remove carbon monoxide from the air inhaled by the wearer; they can easily be carried by miners throughout the working shift. This paper considers the physiological requirements governing the design of self-rescue apparatus, and discusses the data that are available on the composition of mine air after fires and explosions. On the basis of this information, suggestions are made for the performance that should be attained by self-rescue apparatus, including limits for temperature of the inhaled air and for breathing resistance, as well as for carbon monoxide concentration. Laboratory tests of currently available self-rescuers are described.

Wood, P. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Behaviour of People in Fires," *Fire Research Note No. 953,* Joint Fire Research Organization (November 1972)

Subjects: Behavior; Building; Fire; Persons; Smoke

Author's Summary

Under a contract from the Fire Research Station a study has been made of the behaviour of people in fires, using as a main data source a questionnaire administered by Fire Brigade Officers at the scenes of fires. A general analysis has been made of the things people did and more intensive studies have been made of two aspects, evacuation of the building and movement through smoke. A summary of the main findings is given.

L. Operations Research, Mathematical Methods, and Statistics

Haines, D. A., Main, W. A., and Crosby, J. S. (North Central Forest Experiment Station, St. Paul, Minnesota) "Forest Fires in Missouri," *U.S. Department of Agriculture Forest Service Research Paper NC-87* (1973)

Subjects: Fire protection; Fire control; Fire cause; Fire weather

Authors' Abstract

Describes factors that contribute to forest fires on two of the State of Missouri's Protection Districts and the Clark National Forest. Includes an analysis of fire cause, annual distribution, weather, and activity by day of week; also discusses multiple-fire day.

Fire Research Station (Borehamwood, Herts., England). "United Kingdom Fire and Loss Statistics, 1970. Statistical Analysis of Reports of Fires Attended by Fire Brigades in the United Kingdom during 1970," Joint Fire Research Organization, Borehamwood, Herts.

Subjects: Fire loss; Statistics; United Kingdom fire losses, 1970

Preface and Table of Contents

The tables of statistics in this volume have been compiled by the Fire Research Station from reports of all fires (other than those confined to chimneys) attended by local authority fire brigades in the United Kingdom during 1970. Information on the larger losses (direct losses estimated to have been £10,000 or more) has been provided from insurance sources.

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Time of call to large fires (Not in buildings)
Control time of large fires
Jets used to extinguish large fires (In buildings)
Jets used to extinguish large fires (Not in buildings)
Behaviour of fire protection devices

Silcock, A. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Survey of Fires in Buildings—Third Report. The Use of Information Obtained from Fire Surveys," *Fire Research Note No. 949,* Joint Fire Research Organization (January 1973)

Subjects: Building; Cost-benefit; Escape means; Regulations; Survey; Fire

Author's Summary

The previous two reports in this series gave details of the general scope of the pilot exercise and methods by which it was carried out. In addition the nature of the information obtained was illustrated by preliminary analyses of the house and industrial fires surveyed. Some brief comments on the use of the information were made.

This report indicates a method of assessing the nation wide effects of applying conclusions drawn from the results of limited numbers of surveys and considers the use of the information for specific purposes.

Stacey, G. S. (Ohio State University, Columbus, Ohio) "The Allocation of Resources in Municipal Fire Protection," Ohio State University, Columbus, Ohio (1973)

Subjects: Resource allocation; Allocation of resources; Municipal fire protection; Fire protection, municipal

Author's Summary

Local governments constantly face the problem of how to allocate resources in providing public services. This research is an attempt to develop a method to improve the expenditure decision for one local government service—fire protection. The reasons for a suboptimal allocation of resources in fire protection are discussed and a model to allocate optimally is developed.

The model used in this study is based on the principle of maximizing protection to the city, subject to a set of constraints. The model is computer-based and utilizes a standard linear programming package. The major components of the model include an objective function based on a definition of protection, a set of constraints consisting of resource constraints, protection constraints and a budget constraint, and an allocable resource—the fire fighting unit.

The primary data source for this study was records of response to fire by the fire department of Dayton, Ohio. The physical characteristics of the Dayton fire department were also used to model the fire protection system. Secondly, census data were used for estimates of the distribution of population in the City of Dayton. Other data were obtained from zoning maps, discussions with city officials and discussions with representatives of insurance companies.

The results of the runs of the linear program model are presented as a comparison between the actual distribution of equipment and the distributions prescribed by maximizing the various objective functions. The use of the model for decision-making is illustrated by example.

The fire protection system approximated by the model in this research is simplified to facilitate application to a real problem and to accommodate limitations in the data. Elements of time, types of units, different distance factors and the cost of moving the equipment are handled in this model by simplifying assumptions. The framework for expansion of the model to incorporate additional detail is discussed in the final chapter.

This approach to assisting in the resource allocation problem for fire protection results in recommendations for reallocation that can lead to savings by the department. In addition, insight is provided to answering the question of how the existing system may be biased to favor protecting property or population.

M. Model Studies and Scaling Laws

Hopkinson, J. S. (Joint Fire Research Organization, Borehamwood, Herts., England) "Fire Tests on an Air-Supported Structure," *Fire Research Note No. 955,* Joint Fire Research Organization (December 1972)

Subjects: Building, air-supported; Fire hazard; Escape means; Fire tests

Author's Summary

Concern over the stability of air-supported structures under fire conditions has been expressed by those involved with safety of persons in places of assembly and over the safety of contents by those concerned with insurance of property.

Tests have been conducted to investigate the behaviour of a structure with high- and low-level perforations, the effect of smoke and fires on escape, the characteristics of the fabric material, and the fire fighting problems.

From these tests it was found that smoke is vented by any opening made in

the structure, and normal exits may become smoke-logged when they are opened. The structure remains inflated with small fires even though the fabric is punctured, aided by the buoyance effect, but collapses quickly with a large fire. Fires can be put out from inside if they are small and from outside if the collapsed fabric lies flat on the ground.

Heselden, A. J. M., Wraight, H. G. H., and Watts, P. R. (Joint Fire Research Organization, Borehamwood, Herts, England) "Fire Problems of Pedestrian Precincts: Part 2. Large-Scale Experiments with a Shaft Vent," *Fire Research No. 954,* Joint Fire Research Organization (December 1972)

Subjects: Shopping mall; Smoke; Smoke spread; Vents; Ventilation; Escape means; Screen

Author's Summary

The results of large-scale experiments on the prevention of smoke travel along covered pedestrian malls by natural venting are presented and discussed.

Fires of 0.6, 1.1 or 3.2 MW output were set in a "shop" giving on to a covered "mall" or arcade about 17 m long, 6 m wide and 3 m high. Measurements of the temperature, layer depth, rate of flow, and opacity of the smoke-laden hot gases were made in the mall with and without venting and with and without a ceiling screen in the mall and a fascia board in the front of the shop.

The experiments show that the spread of smoke along the mall can be prevented by the combined action of a venting system and roof screens—neither being effective alone.

Because substantial quantities of air mix with the smoke layer as it passes along the mall, the venting system should have a larger capacity than would be required for fires in simple single-storey buildings. A number of small vents spaced well apart over the whole ceiling are likely to be much more effective than a single large vent of the same nominal venting capability.

Phillips, H. (Safety in Mines Research Establishment, Department of Trade and Industry, Buxton, Derbyshire, England) "A Nondimensional Parameter Characterizing Mixing Processes in a Model of Thermal Gas Ignition," *Combustion and Flame* **19,** 181–186 (1972)

Subjects: Mixing; Ignition; Dimensionless numbers; Scaling; Modeling

Author's Abstract

Gas ignition processes are characterized by a pocket of hot gas into which is mixed the surrounding flammable atmosphere. The rate of mixing into the pocket depends on a constant dimensionless parameter whose numerical value is estimated by making various assumptions concerning the nature of the mixing processes. The use of the parameter in the elementary analysis of a number of ignition situations is discussed.

N. Instrumentation and Fire Equipment

Jeltes, R. and Burghardt, E. (Safety in Mines Research Establishment, Sheffield, England) "Automatic Gas Chromatographic Measurement of C_1-C_5 Hydrocarbons in Air," *Atmospheric Environment* ***6***(11), 793–805 (November 1972)

Subjects: Chromatograph, automatic; Hydrocarbon analysis

Safety in Mines Research Establishment
Abstract, by Permission

The development of an automatic gas chromatographic method for measurement of hydrocarbons in air is described. With this method an important fraction of the hydrocarbons in the atmosphere, the C_1-C_5 hydrocarbons, can be separated and measured on a time-averaged basis. Compared with other measuring methods for hydrocarbons it is a relatively simple, direct, and inexpensive method for sensitive and quick measurement. The high sensitivity of this method and the relative freedom from interference, compared for example with similar commercial apparatus, can be attributed to a number of apparently small, supplementary provisions. After a discussion of the reasons for the selection of the method and a description of the apparatus, including technical data, reference is made to analytical results intended to give an impression of the possibilities of the apparatus. 39 refs., 5 figs., 7 tables.

Jones, D. C. and Broido, A. (Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, Berkeley, California) "Apparatus for Determining Glowing Combustibility of Thin Fuels," *Journal of Fire and Flammability* **2,** 77 (January 1971)

Subjects: Glowing combustion; Combustibility; Thin fuels

Authors' Abstract

Leaflike samples, approximately 8 cm in diameter, are held at the end of a mechanical arm which reproducibly controls sample movement during the ignition and burning process. Glowing combustion is induced by bringing the sample into contact with a small loop in an electrically heated nichrome wire. The ultimate burned-out area is measured in an ultraviolet detection system utilizing a vacuum photodiode. The system, calibrated using black construction paper with a series of standard holes in the range 0.002 to 20 cm^2, has a sensitivity close to 5 mv/cm^2.

Senior, M. (Joint Fire Research Organization, Borehamwood, Herts., England) "A Preliminary Investigation into the Visualization of Gas Layers," *Fire Research Note No. 952,* Joint Fire Research Organization (December 1972)

Subjects: Holography; Gases; Layers; Visualization

Author's Abstract

This paper describes a series of experiments designed to investigate the possibility of the visualization of gas layers using optical methods. Several optical methods are considered including the possible application of holographic interferometry. Good results have been obtained using schlieren techniques in the visualization of carbon dioxide/air gas layers produced in a tank 1.28 metres in length.

It is felt that double exposure and real time holography will prove to be extremely effective in gas layer visualization due to their inherent high sensitivities and comparatively simple experimental techniques.

O. Miscellaneous

Fire Problems Program: Annual Summary Report, 1 July 1972 - 30 June 1973, Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland under a grant from the National Science Foundation (RANN Program GI-34288x) Program Director: A. G. Schulz; Principal Investigators: R. M. Fristrom and W. G. Berl

Subjects: Education; Systems analysis; Combustion; Fatalities; Casualties; Toxic gases; Fire science directory; Command and control kit

Report Summary

ABSTRACT OF THIRD YEAR ACCOMPLISHMENTS

Tasks pursued during the third year of the APL Fire Problems Program continued, with certain adjustments, within the framework of the four major topical areas established for the previous year, namely:

I. Education and Information (eight tasks): fire service and public education in fire was promoted by conferences, colloquia, audio-visual material, a motion picture film, and compilation of reference works. In addition, broad-scope investigation was initiated on fire information, leading to the development of a model fire information center. A highlight in this area was a symposium and workshop on "The Problems of Teaching the Fire Sciences."

II. Systems Analysis and Development (five tasks): work has continued on data gathering and analysis of fire incidents in an urban area (Alexandria, Virginia) and field testing was undertaken of a fireground Tactics Display Case. The tactics display concept is being extended to a Console with added features, and ultimately to a fully equipped Mobile Tactical Unit that will serve as a fireground command, control, and communications center. Communications problems of a large metropolitan fire department (Baltimore, Maryland) were studied, and recommendations were submitted. Also, a predevelopment evaluation was made of an external elevator designed to raise fire fighters to upper floors of high-rise buildings during emergencies.

III. Combustion Research (two tasks): efforts were directed toward a basic understanding of the principles of chemical flame inhibition processes for the purpose of determining optimum characteristics and limits of chemical extinguishants. During the period, work was completed on the simple flame theory for inhibition chemistry, and the apparatus for flame injection studies of the kinetics of inhibitors was tested. Three papers describing the work are being prepared.

IV. Fire Casualty Studies (five tasks): a comprehensive medical and toxicological investigation was conducted on individuals who died or were injured by fire. These studies are being extended to fire fighters exposed to fire environments.

As awareness of the APL Fire Problems Program spreads, increasing opportunities arise for interaction in a helpful way with fire departments and members of the fire service, with fire science educators and students, and with the public in general. The current year has been especially fruitful in advancing on-going tasks and in initiating necessary extensions of effort into important related areas.

Compared with the preceding year, greater emphasis and effort were devoted to Fire Casualty Studies and to Systems Analysis and Development. These areas hold promise of great reward. Moreover, important goals are reachable within short or intermediate time spans.

Following the pattern set from the beginning, members of the Fire Problems Program continued to actively share results and experiences through publications, lectures, and presentations. This activity is reflected in the listings below. In one form or another, outputs from the Program have been sent to almost 1000 individuals and organizations in the United States, Canada, Europe, and the Far East.

Area I—Education and Information

Task A—Colloquia on Fire Problems

A series of colloquia on a variety of fire problems was held with a twofold purpose: to provide a forum for discussion for fire-science/fire-practitioner audiences in the Washington-Baltimore area, and to make these lectures available to a nationwide audience by means of audio and video recordings.

Task B—Fire Sciences Dictionary and Source Book (Revision)

A preliminary draft of a multidisciplinary FIRE SCIENCES DIRECTORY AND SOURCE BOOK, containing over 4500 terms, was completed in 1971. Over 300 copies were circulated for review and comment. Since this first printing, many suggestions have been received for improving the text, and almost 2000 new terms have been collected. The new terms will be selected for inclusion. As soon as practicable, a schedule will be established to revise the draft and submit the manuscript for publication.

Task C—Directory of Workers in the Fire Field

The *Directory of Workers in Fire Research* proved to be a useful reference tool. However, it lacked indexes and, as is natural with all directories, was becoming obsolete because of job changes, retirements, etc. In response to a request by the NASA Aerospace Safety Research and Data Institute, Lewis Research Center, and in cooperation with the Fire Technology Division of the National Bureau of Standards, the original Directory was revised, enlarged, and indexed. The updated compilation was published and distributed by NASA ASRDI.

Task D—Translation of Soviet Abstracts Journal "Fire Protection"

An effort was initiated to translate six issues of the new monthly Soviet abstracts journal, *Pozharnaya Okhrana (Fire Protection)*, which first appeared in January 1972. This journal contains abstracts from many sources not usually covered by the more familiar secondary publications such as *Fire Research Abstracts and Reviews* or *References to Scientific Literature on Fire*. One issue, March 1972, has been translated and distributed with a questionnaire to determine the usefulness of the abstracts journal to the U.S. fire community.

Task E—Problems in Teaching the Fire Sciences

A seminar and workshop on "The Problems in Teaching The Fire Sciences" was held on 1, 2, and 3 March 1973. It was attended by 70 representatives and instructors of fire science/technology in community colleges throughout the United States and by fire department officials concerned with instructional matters. Proceedings of the discussions have been prepared for publication. Plans for a follow-up symposium in the spring of 1974 are under way.

Task F—Conference on Fireground Command, Control, and Communications

A great diversity exists in procedures and equipment used to provide information about and control of fireground operations. An exchange of information at a symposium and workshop on the specialized topic of command, control, and communications on the fireground would be of significant value to the fire service in coordinating programs and defining aims. A conference on fireground command, control, and communications is planned for the winter of 1973/1974. Organization has begun but is still in the very early stages.

Task G—Fire Safety Film

A fire safety film entitled "Don't Get Burned" has been completed. It was made primarily by high school students under the professional guidance of the APL motion picture group. The film is designed to present a fire safety message to an audience of high school age. A means to provide nationwide distribution and screening is being sought.

Task H—NSF/APL Exhibit

To bring the NSF/RANN Program to the attention of the fire service and other fire-oriented people, a display was prepared by APL highlighting the scope of the RANN Fire Research Program and the major tasks in the APL Fire Problems work. The display, manned by both RANN and APL representatives, was exhibited at the National Fire Protection Association Annual Meeting in St. Louis, 14 through 18 May 1973.

Task I—Fire Information Center

The desire has been expressed in many quarters of the fire community for more complete and reliable data and better access to fire information. A wealth of information exists, but it is scattered throughout the scientific and technical literature. The bibliographic control over this literature lacks the fire community's viewpoint, and therefore literature searches for fire topics are difficult. To make fire information more easily accessible to members of the fire service and people working on fire problems, it should be brought together under bibliographic control that has a fire community's viewpoint.

Area II—Systems Analysis and Development

Task A—Fire Incident Analysis

Data associated with a large sample of fire incidents are being recorded and analyzed to identify specific problem areas and significant variables, quantify relationships among these variables, and depict trends. An important consideration in this work is how data from fire incidents should be collected and analyzed to produce meaningful information and lead to valid conclusions. Several tasks under the APL Fire Problems Program are currently benefiting from this work.

Task B-1—Fireground Command and Control System—Tactics Display Case

The design of an economic and practical fireground command and control system that could be obtained and used by every level of fire department was undertaken in 1971. A systems analysis is under way to determine the functions that should be covered by the system. Close contact has been made with the Hillandale, Maryland Volunteer Fire Department in an attempt to assess the uses and practicality of the tactical control equipment. The aim is to design and build prototypes of the fireground command and control system and implement their use. The system will aid the fireground commander in making tactical decisions. The primary design criteria for this system are that it be economically available to fire departments and practical to use. The system is intended also to function as a training device and a preplanning tool.

Task B-2—Fireground Command and Control System—Tactics Console

A microfiche reader and the Tactics Display Case were combined in a compact unit called the Tactics Console. The first unit is mounted in the cab on Engine 121 of Company 12 of the College Park, Maryland VFD. The operational feasibility of this command and control concept will be evaluated during the next year.

Task B-3—Fireground Command and Control System—Mobile Tactical Unit

The concepts advanced during the development of the Tactics Display Case and Tactics Console will be used as the nucleus of a Mobile Tactical Unit (MTU). The MTU will function as a mobile command, control, and communication center during such emergencies as fires. A vehicle has been purchased by the Hillandale, Maryland VFD to serve as the first MTU. APL will provide the design layout of the tactical control functions of the MTU.

Task C—"Flying Tram" Predevelopment Evaluation

A concept for a device to obtain access to a high-rise building from the exterior was presented in a previous report of the APL Fire Problems Program. The device has come to be known as the "Flying Tram." It consists of a carrier suspended by cables from a roof-mounted truck, which contains motors for its own lateral motion and for vertical motion of the carrier. The truck can move on rails around the edge of the roof and thus gives access to any face of the building. Vertical and lateral movement of the carrier would be controlled both from the carrier and from a ground-controlled override system that could initially bring the carrier down to the ground or be used to move personnel and the carrier out of a danger area.

Task D—Survey of Communications in an Urban Fire Department

At the invitation of the Baltimore City Fire Department, APL has reviewed fire-communication practices in Baltimore. The Department approached APL because it faced an increasing requirement to replace old equipment and it wanted an independent, outside assessment of its communications system and advice on state-of-the-art capabilities. A study was made of the structure of the system and of procedures and equipment.

Area III—Combustion Research

Task A—One-Zone Premixed Flame Model

Flames are known to be affected by so-called "inhibitors" to the point of actual extinguishment if the inhibitor is present in sufficient concentration. It is generally agreed that inhibitors that are effective in small concentrations interfere in some crucial way with the chemical reactions within the reaction zone of the flame. A proper understanding of inhibitors requires knowledge of the specific reactions that are interfered with and how this, in turn, affects the flame, its structure, and its ability to function.

Task B—Flame Inhibition Chemistry

Volatile halogen compounds form an important class of chemical inhibitor for flame extinguishment. The attractiveness of chemical agents is that the quantities required to produce the desired effects are generally much smaller than with physical agents. A detailed theory of chemical extinguishment (often called inhibition) depends greatly on the reaction rates of the halogen compounds with radical species produced in a given flame. Unfortunately, there is very little reliable reaction rate information for high-temperature flames. The immediate problem to be solved is a determination of the reaction rates for hydrogen radicals reacting with the methyl halides (CH_3Br, CH_3Cl, and CH_3F) in a hydrogen-rich hydrogen/oxygen flame.

Area IV—Fire Casualty Studies

Task A—Fire Fatalities Study

This program was initiated in October 1971 and is operational. To gain an understanding of the mechanism of fire fatalities, both individually and statistically, information is being derived from pathological and toxicological studies correlated with characterizations of the fire scenes and special laboratory studies. The mechanics of the Medical Examiner's work and the fire scene data collection have been established. Data are available on 101 fatalities.

Task B—Biochemical Studies of Tissues and Fluids of Fire Victims

To aids in clarifying fire death mechanisms and ultimate causes of death, biochemical information, supplementary to standard autopsy data, must be obtained. Qualitative and quantitative methods have been established for determining trace metals in whole blood and lung tissue samples. Analysis of samples from fire victims is in progress. A system for examining toxic gases sorbed into lung fluid has been designed and is being used.

Task C—Nonfatal Fire Injury Study

This task is an extension of the fatality study (Task IVA) in a further attempt to understand the problems associated with an insult to the respiratory system through by-products of a fire. By means of blood samples and medical follow-up data, we will attempt to assess the degree of exposure to toxic gases and to estimate the occupational hazard for firefighters. Negotiations to implement the program were formally initiated in December 1972. Permission was received from necessary agencies to work out the implementation method with the Baltimore Fire Department in July 1973. The Program is expected to be operational in October 1973.

Task D—Toxic Gas Accumulations in Building Fires

The injurious effects resulting from the inhalation of toxic gases are being studied at APL as a task in the Fire Problems Program. Data from two test burns were obtained to supplement previous data on the accumulation of toxic gases in rooms adjacent to the fire room.

Task E—Portable Automatic Fire Gas and Smoke Sampling Device

Many laboratory experiments have been carried out on building materials, furniture, paint, and household articles to determine the types of combustion products to which a firefighter might be exposed when he is involved in a house fire. However, such information on full-scale fires is rare. Tests on full-scale house fires are expensive and are difficult to replicate and instrument for detailed analysis of variations. Instrumentation of uncontrolled and unexpected fires is rarely possible. In order to gain an understanding of the smoke/gas environment, a program was initiated to develop automatic gas sampling devices that could be carried into the fire environment to take samples at predetermined time intervals. Such a device must require minimum effort on the part of the person carrying it. A large number of samples obtained under a variety of fire conditions, should provide new insights into generation and movement of toxic gases in burning structures.

PUBLICATIONS

Books and Special Publications

1. "The Problems in Teaching the Fire Sciences," *Proceedings of Symposium and Workshop Held at the Applied Physics Laboratory, 1-3 March 1973.* R. L. Tuve, Ed., APL/JHU FPP B73-1 (February 1973)
2. B. W. Kuvshinoff (APL), S. B. McLeod (NBS), and R. G. Katz (NBS), *Directory of Workers in the Fire Field,* NASA CR-121149 (February 1973)
3. R. Fristrom, "Flames and Flame Structure," *Encyclopedia of Chemistry,* 3rd. ed., Van Nostrand Reinhold Co., N. Y., 1973, pp. 441–443.
4. W. G. Berl, "Combustion," *Encyclopedia of Chemistry,* 3rd. ed., Van Nostrand Reinhold Co., N. Y., 1973, pp. 289–291.

Journal Articles

1. J. E. Creeden, R. M. Fristrom, C. Grunfelder, and F. J. Weinberg, "A Large Area Interferometer Differential Laser for Fire Research," *J. Phys. D; Appl. Phys.,* Vol. 5, No. 6, June 1972, pp. 1063–1067 (Also published as APL/JHU Reprint 1412).
2. B. M. Halpin and H. E. Hickey, "Tactics Case Designed for Command and Control," *Fire Engineering,* Vol. 126, No. 1, January 1973, pp. 50–51 (also published as APL/JHU Reprint 1464).
3. B. W. Kuvshinoff, "Soviet Fire Information Dissemination Media," *Fire Research Abstracts and Reviews,* Vol. 14, No. 3, 1972, pp. 227–231 (also published as APL/JHU Reprint 1512).
4. R. Fristrom, B. Kuvshinoff, and M. M. Robison, "Bibliography on Flame Structure" (to be published in *Fire Research Abstracts and Reviews,* Vol. 15, No. 2).

Symposium Papers

S10 R. M. Fristrom, "Flame Structure," presented at Polymer Conference Series: Fundamentals of Flammability and Combustion of Materials, University of Utah, 10–14 July 1972.

S11 R. M. Fristrom, "Fire Research in the United States of America," Plenary Lecture at Belgian Section of the Combustion Institute, March 1973 (to be published in *Belgian Combustion Reviews*).

S12 R. M. Fristrom, "Some Activities of the Committee on Fire Research of the National Academy of Sciences of the United States," presented at 3rd International Symposium on Combustion Processes, Kassimirs, Poland, September 1973 (to be published in *Polish Archives of Combustion Processes*).

Topical Reports

1. R. M. Fristrom, B. W. Kuvshinoff, and M. M. Robison, *Bibliography on Flame Structure (1934–1972),* APL/JHU FPP TR13, January 1973.

2. R. M. Fristrom and B. W. Kuvshinoff, *Bibliography on Flammability,* APL/JHU FPP TR14, June 1973.
3. B. W. Kuvshinoff and L. J. Holtschlag, *Soviet Abstract Journal: Section 68, Fire Protection,* APL/JHU FPP TR16, January 1973.
4. B. M. Halpin and H. E. Hickey, *Fireground Command and Control Tactics Display Case* (Preliminary Report), APL/JHU FPP TR22, April 1973.
5. G. L. Ordway and J. R. Hamblen, *Communications Systems, Equipment, and Message Traffic in a Large Metropolitan Fire Department,* APL/JHU FPP TR23, July 1973.

LECTURES AND PRESENTATIONS

1. W. G. Berl, "Fire as an Urban Disease," presented at International Seminar on Human Settlements, Athens Center for Ekistics, Athens, Greece, 18–20 July 1972.
2. W. G. Berl, "Colloquium on Elementary Reactions in Combustion," presented at 14th Symposium (International) on Combustion, University Park, Pa., 20–25 August 1972.
3. W. G. Berl, "Summation of Remarks," presented at Second Annual Meeting of Student Competitions on Relevant Engineering, Inc., Georgia Institute of Technology, Atlanta, Ga., 11 November 1972.
4. W. G. Berl, "The Problems and Prospects of Fire Research," presented at University of Maryland, College Park, Md., 11 April 1973; also at Rutgers University, New Brunswick, N. J., 20 April 1973.
5. N. J. Brown, "Molecular Dynamics—Energy Transfer in the Li^+, OH_2 Systems," presented at University of Goettingen, Goettingen, West Germany, 13 June 1973.
6. R. M. Fristrom, "Fire and Flame Studies Utilizing Molecular Beam Sampling," presented at Molecular Beam Sampling Conference, Midwest Research Institute, Kansas City, Mo., 25–27 October 1972.
7. R. M. Fristrom, "Combustion and Inhibition Chemistry," presented at Department of Chemistry Colloquium, Catholic University, Washington, D. C., 3 November 1972.
8. R. M. Fristrom, "The Combustion of Polymers," presented at Flammability Colloquium, Wilmington, Del., 11 November 1972.
9. B. M. Halpin, "Medical and Biomedical Studies of Fire Deaths and Casualties," presented at Flammable Fabrics Seminar, National Bureau of Standards, Gaithersburg, Md., 2 October 1972.
10. B. M. Halpin, "APL Fire Research Program," presented at Society of Fire Protection Engineers Meeting, University of Maryland, College Park, Md., 7 February 1973.
11. B. M. Halpin, "Fire Death Studies," presented at Conference on Fire Safety for Buildings: Research—Practice—Needs, sponsored by NSF, NBS, and HUD, Airlie House, Va., 10 July 1973.
12. B. M. Halpin, "A Study of Fire Deaths," presented at 77th Annual Meeting of the National Fire Protection Association, St. Louis, Mo., 18 May 1973.
13. L. Hart, "The Point Source Technique for the Chemical Rate Constant

Determinations," presented at Eastern States Combustion Institute Meeting, 1973.
14. H. E. Hickey, "Tactical Aids for a Total Command-Control-Communications System," presented at 77th Annual Meeting of the National Fire Protection Association, St. Louis, Mo., 18 May 1973.
15. B. W. Kuvshinoff, "APL/NSF Fire Problems Program," presented at Maryland State Volunteer Firemen's Association Meeting, West End Firehouse, Annapolis, Md., 1973.
16. G. L. Ordway, Participant in Mayor's *ad hoc* Committee on Communications Coordination, Baltimore, Md., June 1973.

APL FIRE PROBLEMS COLLOQUIA

C26-72 A. Swersey (Director, Fire Research, New York City Rand Institute)
"Current Research for the New York City Fire Department"
12 October 1972

C27-72 D. C. Gratz (Silver Spring, Maryland Fire Department)
"A Microfilm Information System for Fire Emergency Operations"
2 November 1972

C28-72 C. C. Chandler (U.S. Forest Service, Washington, D. C.)
"Why Not Let Forest Fires Burn?"
9 November 1972

C29-72 J. A. Rockett and H. Utech (U.S. National Bureau of Standards, Washington, D. C.)
"Design Problems of Fire Fighters' Equipment (The Fire Fighter's Turnout Coat and Other Challenges)"
14 December 1972

C30-73 J. Christian (National Commission on Fire Prevention and Control, Washington, D. C.)
"Fire Research Gaps"
11 January 1973

C31-73 J. F. Burke (Burns Institute, Massachusetts General Hospital, Boston, Mass.)
"Treatment of Burns"
22 February 1973

SCORE (Student Competitions on Relevant Engineering, Inc., Tufts University, Medford, Massachusetts).

In an effort to demonstrate through student projects how enginering technology can be put to use in combating fire deaths and injuries, current SCORE activities include:

- Testing of cable-operated escape chairs by students at the University of Houston and a similar device at the University of Wisconsin that saves time by automatically retracting after each rescue.

- Firing of breathing masks and protective blankets to trapped occupants through use of rescue cannons designed by teams at Clarkson College of Technology and the University of Florida.
- Development of an all-terrain vehicle at Iowa State University which can drive across a field, through brush, or other rough terrain to reach a fire which might otherwise burn out of control.
- Use of a fire robot equipped with fire sensors and extinguishing chemicals, designed at the University of Kentucky to seek out and suppress underground mine fires by remote control.
- Replacement of the traditional fireman's rubber and cotton coat with a head-to-toe life-support suit, a team effort at the University of Texas at Arlington. A liquid air backpack system provides cooling and breathing source without excessive bulk.
- Development of home fire-detection systems that include daily automatic testing, attempts to reduce false alarming, and an automatic notification of fire departments.

This segment, known as Students Against Fires (SAF), is set for final testing May 1–4, 1974.

BOOKS

Proceedings of European Symposium on Combustion (Held at Sheffield, England, 1973) F. Weinberg, ed. Academic Press, London, England.

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13. The Role of Chain Termination in Modelling Cool Flames—F. Baronnet, M. P. Halstead, A. Prothero and C. P. Quinn
14. Elementary Steps in Hydrocarbon Combustion: The Reactions of Butylperoxy Radicals—J. A. Barnard and R. D. Handscombe
15. Gas Phase Oxidation of Alkenes: Propagation Reactions—F. McKeon, D. J. M. Ray, A. Redfearn, R. Ruiz Diaz, and D. J. Waddington
16. Elementary Processes in Aldehyde Oxidation at Low Temperatures—D. J. Dixon, G. Skirrow, and C. F. H. Tipper
17. Preflame Processes in the Ozone Activated Oxidation of Methylcyclopentane—V. Caprio, A. Insola, and R. Barbella
18. On the Mechanism of Propylene Epoxidation—L. Sümegi, A. Gedra, A. Németh and D. Gál
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Palmer, K. N. (Head of the Industrial and Toxic Hazards Section at the Fire Research Station, Borehamwood) **Dust Explosions and Fires.** London, England, 1973.

Publisher's Description and Contents

This book is a comprehensive account of both the practical and theoretical aspects of dust explosions and fires. The problem is discussed in detail and an up to date description of the technical background of the subject is given. A critical discussion of research investigations into the combustion of dusts on both laboratory and full industrial scales is also included.

Attention is paid to dusts which have traditionally been regarded as an explosion hazard, either because of their widespread use or their severe explosibility, and also to newer industrial processes involving dust explosion and fire hazards. Clear accounts of protection methods and hazard assessment have also been included.

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Fire Management. Published quarterly by the Forest Service of the United States Department of Agriculture, Washington, D. C.*

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Formerly known as *Fire Control Notes,* this journal is the house organ of the Forest Service and the new name reflects their increased concern with prevention of unwanted fires and the judicious use of fire as a means of protecting our environment. Managing editor is Sigrid Benson; technical coordinator, Edwin J. Young.

Meetings

Symposium on Air Quality and Smoke from Urban and Forest Fires, Committee on Fire Research, National Academy of Sciences—National Research Council, held at Colorado State University, Fort Collins, Colorado, October 27–30, 1973.

Subjects: Smoke; Forest fires; Air quality; Agricultural fires; Prescribed burns

Reviewed by J. S. Barrows

The Air Quality and Smoke Symposium was sponsored by the Committee on Fire Research to review some of the problems and issues involved. It was held at the Colorado State University, Fort Collins, Colorado, October 27–30, 1973. Topics discussed were:

1. Effects of smoke from free burning fires on air quality. The symposium brought some of the available information into sharper focus. The hazard of decreased visibility and aesthetic aspects of smoke are well recognized. Health aspects are less well understood or documented. Perhaps the committee should consider development of a summary paper on this subject including clear identification of the major voids in knowledge that should be targets of future research.
2. Future role of prescribed fire. The symposium presented the case for prescribed fire and its importance in reducing fire hazards, control costs and damages. The symposium also presented the views of air pollution authorities against prescribed fire. This issue is of critical importance to agriculture and forest management. Since burning of agriculture waste augments agriculture yields the risks of forest fires will increase if prescribed burns are not allowed. The Committee should play a continuing role in analyzing and presenting pertinent information on this subject.
3. Air quality problems in wildfire management. In the United States both the park and forest service now plan that certain wildfires will be allowed to burn in wilderness areas and national parks. The smoke from these wildfires may have more serious consequences than those from prescribed fires where man can call the shots and prevent serious deterioration of air quality. Some forest fire officials believe wilderness fire management policies may threaten the advances made in smoke management for prescribed fire programs. The Committee should keep well informed on this volatile

subject and be prepared to develop an overview on the issues involved and the alternative solutions.

4. The communication link between fire scientists, fire control and air pollution officials. The symposium helped to forge this link. We should take follow-up action.

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College of Forestry & Natural Resources
Colorado State University

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Dr. A. R. Chamberlain, President
Colorado State University

Keynote Address
Dr. Carl W. Walter, Chairman
Committee on Fire Research
National Academy of Sciences

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Mr. Theodore A. Schlapfer
Regional Forester, U.S. Forest Service
Portland, Oregon

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Underwriters' Laboratories, Inc.
Northbrook, Illinois

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Mr. Mike Jones
Environmental Protection Agency
Research Triangle Park, North Carolina

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Mr. Robert Cooper
Southern Forest Fire Laboratory
U.S. Forest Service
Macon, Georgia

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Dr. Vincent J. Schaefer
Atmospheric Sciences Research Center
State University of New York
Scotia, New York

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University of Utah
Salt Lake City, Utah

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Dr. Ellis Darley
California Statewide Air Pollution Center
University of California
Riverside, California

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Department of Atmospheric Sciences
Colorado State University
Fort Collins, Colorado

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Washington State University
Pullman, Washington

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Mr. Michael Fosberg
Rocky Mountain Forest and Range Experiment Station
Fort Collins, Colorado

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Defense Civil Preparedness Agency
Washington, D. C.

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Mr. Robert Coleman
Environmental Protection Agency
Research Triangle Park, North Carolina

Air Quality Standards for Smoke Particulate Matter in Canada
Mr. Charles Newbury
Air Pollution Control
Department of Environment
Ottawa, Ontario

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—Montana
R. Clark Neilson
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—Oregon
Mr. Harold Patterson

Division of Air Quality Control
Portland, Oregon

—Georgia
Mr. Robert Collum, Chief
Air Quality Control
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Atlanta, Georgia

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Mr. Hugh Mobley
U.S. Forest Service
Macon, Georgia

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Director of Rocky Mountain Forest and Range Station
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U.S. Forest Service
Washington, D. C.

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Pacific Northwest Forest and Range Experimental Station
Seattle, Washington
and
Mr. Owen Cramer
Pacific Northwest Forest and Range Experiment Station
Portland, Oregon

Prescribed Fire Technology for Minimizing Smoke Hazards
Mr. Stephen S. Sackett
Southern Forest Fire Laboratory
Macon, Georgia

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University of California
Berkeley, California

Smoke Factors in Wildfire Management Programs
Mr. Robert Mutch
Northern Forest Fire Laboratory
U.S. Forest Service
Missoula, Montana
and
Mr. George Briggs
Sequoia—Kings Canyon National Park
Three Rivers, California

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Dr. Robert Dils, Chairman
Dean of the College of Forestry and Natural Resources
Colorado State University

Goals of a National Program in Smoke Research

Mr. James Smith
Environmental Protection Agency
Research Triangle Park, North Carolina

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Moderator:

Mr. Craig Chandler, Director
Fire & Atmospheric Sciences Research
U.S. Forest Service
Washington, D. C.

Panelists:

Smoke Composition

Mr. James Smith
Environmental Protection Agency
Research Triangle Park, N. C.

Fuels

Mr. Hal Anderson
Northern Forest Fire Laboratory
U.S. Forest Service
Missoula, Montana

Fire Behavior

Mr. Dave Williams, Director
Forest Fire Research Institute
Department of Environment
Ottawa, Ontario

Meteorology

Dr. Elmar Reiter, Head
Department of Atmospheric Sciences
Colorado State University

Logging Slash

Dr. Barney Dowdle
University of Washington
Seattle, Washington

Panel Discussion: Government and Industry Programs for Smoke Control

Moderator:

Mr. W. R. Tikkala, Director
Cooperative Forest Fire Control
U.S. Forest Service
Washington, D. C.

Panelists:

National Forests

Mr. Henry DeBruin, Director

Fire Management
U.S. Forest Service
Washington, D. C.

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Mr. Ralph Winkworth
State Forester, North Carolina
(President of National Association of State Foresters)

Department of Interior Agencies
Mr. James Richardson
Chief of Fire Control
Bureau of Land Management
Washington, D. C.

Forest Industries
Mr. Sharon R. Miller
Chesapeake Corporation
West Point, Virginia

Urban Areas
James J. Morgester
California Air Resources Board
Sacramento, California

Symposium on Fires, Their Detrimental Effects and Applications, Belgian Section of the Combustion Institute, University of Louvain, Louvain, Belgium, May 10, 1973

Subjects: Fire research in the U.S.A.; Explosions; Synthesis gas; Shock ignition; Building fires; Underground combustion; Tests; Belgium Combustion Institute Symposium; Fire symposium; Symposium on fires; Hazards and applications

Organizer: Dr. P. Van Tiggelen, Director, Combustion Laboratory, University of Louvain

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Introduction—Professor J. Ducarme, University of Liege, Belgium

Fire Research in the United States of America—Professor R. M. Fristrom, the Max Planck Institute for Aerodynamics, Göttingen, West Germany (APL, Johns Hopkins, USA)

Uncontrolled Explosions Caused by Synthesis Gas Expansion into the Free Atmosphere—Professor S. Wojcicki, Polytechnic Institute of Warsaw, Poland

Films:

Fire in the Chemistry Department of the Free University of Brussels, and Fire in a Large Brussels Department Store—Mr. J. Ransbotyn, Security Service of the Catholic University of Louvain.

Measurement of the Hazards of Fire Through Standard Tests—Mr. H. Aresu de Sevi, Director of National Association of Fire Protection (Belgium) Brussels, Belgium.

Utilization of Underground Combustion for the Extraction of Petroleum Deposits—Mr. J. Burger, French Institute of Petroleum, Paris, France.

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Fire Research Abstracts and Reviews

National Academy of Sciences

FIRE RESEARCH ABSTRACTS AND REVIEWS

FIRE RESEARCH ABSTRACTS AND REVIEWS will abstract papers published in scientific journals, progress reports of sponsored research, patents, and research reports from technical laboratories. At intervals, reviews on subjects of particular importance will be published. The coverage will be limited to articles of significance in fire research, centered on the quantitative understanding of fire and its spread.

Editor: Robert M. Fristrom, Applied Physics Laboratory
The Johns Hopkins University, Silver Spring, Maryland

Editorial Staff: Geraldine Fristrom, Joan M. Sieber

Volume 15 Number 3

Fire Research Abstracts and Reviews

Committee on Fire Research
Commission on Sociotechnical Systems
National Research Council

NATIONAL ACADEMY OF SCIENCES
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FOREWORD

The issue begins with an article on the fire hazards associated with static electrification which outlines both the practical and scientific aspects of the phenomena. This is followed by a translation which describes in some detail the organization and programs of the Combustion Laboratory of the Warsaw Polytechnic University. Your editor visited the group this year and found it a well-equipped laboratory with a productive program. Fire is only one of their concerns, but there is a lively interest in fire problems both in this and in other Eastern European Laboratories.

The closing note is an agenda and short commentary on the Third International Symposium on Combustion Processes held at Kazimierz, Poland. The meeting provided an interesting counterpoint with the recent European Combustion Symposium (see FRAR 15-2). Scientific exchange between Eastern and Western European Scientific groups is increasing. In the fire area we hope that this climate will continue for such exchanges of information can only benefit all parties.

As the year ends we can look back on a productive though confused period in fire research with reorganizations on every level. The new year will be one of challenges and we hope renewed interest and effort in the area.

FIRE PREVENTION IS ENERGY CONSERVATION IN ITS BEST FORM.

Robert M. Fristrom
Editor

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MEETINGS

Overview of Static Electrification

J. P. Wagner

Gillette Research Institute, Rockville, Maryland

Introduction

Modern man frequently encounters the presence of static electricity, or perhaps more correctly charge separation phenomena, in various common forms, e.g., sliding across an automobile seat and subsequently touching the door handle, walking over a carpet and switching on a light, etc. In these simple examples the charging process results from the mechanics of sliding and walking. We feel and often notice the resulting discharge upon touching the aforementioned objects, which are at lower potentials. We have also observed at least one important controlling parameter, namely high relative humidity (RH), upon noting increased discharges on relatively dry days vs significant decreases with high RH's.

The field of electrostatics has aroused scientific curiosity at least since the time of the ancient Greeks (approx 600 B.C.) with their classical discovery of charging of amber by various materials. In spite of this early discovery and the interests and efforts of various investigators throughout the centuries, much confusion still exists on various aspects in the field. One may ascribe numerous reasons for our basic deficiencies, among which should be included at least the following:

Experimental Difficulties largely caused by the lack of reliable experimental data. Over the past ten years high-precision, multi-purpose electrometers capable of measuring very low currents (picoamps, 10^{-12} amps or less), and high voltages (10^3 volts or more), became commercially available. Experimental data thus generated has helped fill many voids, although huge gaps still exist primarily in dealing with transient charging and discharging processes.

Formalistic Difficulties of a theoretical nature (considered under Fundamental Principles), but partially caused by (1) a lack of reliable experimental data with which to assess the adequacy of the theory, and (2) different sets of electrostatic units which make it difficult for an orderly exchange of information.

The objectives of the present study include:

A review of the field of electrostatics, which includes processes primarily involving liquids and to a lesser extent solids and gases. Published reviews [1-3] appear to be few in number and for the most part, excepting Ref. 1, treat specific areas. Here, the scope is intended to be rather broad, but certainly far from complete, and differs from Ref. 1 in that we resort to use of charge density principles as in Refs. 2, 4–9 rather than the classical streaming or Zeta potential viewpoint of Ref. 1.

An outline of fundamental principles, which involves use of a generalized non-linear partial differential charge transport equation and similitude principles. Problems treated in some depth are turbulent and laminar flow of slightly conducting hydrocarbons through capillaries and flow through porous media. The successes and limitations of these approaches are discussed with an overview of creating a better quantitative understanding of electrical phenomena and stimulating future efforts. Also, inferences are made as to the applicability of the present approach to problems involving solids (including dusts) and gases.

An outline of conditions necessary for creation of a hazardous electrostatic environment, as well as some common methods for control of the attendant hazards.

A consideration of some practical problems.

The overall purpose of this report is to draw attention to a field that has often been neglected so that future studies may evolve in an orderly fashion. Recently, a considerable amount of interest has appeared in commercially important areas, such as electrostatic copying, electrostatic precipitation for pollution control devices, and electrostatic paint spraying.[10]

Hopefully, the successes achieved in these and other industrial concerns will lead to an outgrowth of information which will provide answers to various problem areas in the interesting and challenging field of electrostatics.

General Electrostatic Phenomena

Electrostatic or charge separation phenomena can occur wherever two dissimilar phases are brought into contact as a result of migration of some constituent of the phases up to or across the interface. The reasons for movement and termination of the charge carriers, which may be electrons, ions, or bulk matter have been considered by Harper [11] (Table 1). Following termination, or when equilib-

TABLE 1
Movement and termination of charge carriers [11]

Charge Carrier	Movement	Termination
electrons (metals, semiconductors, *not* insulators)	going to lower energy levels	Fermi levels at same height
	or	
	thermal e. m. f.	hot spot cooled off or capacitance fully charged
ions	going to lower energy levels	levelling complete or shortage of ions
	or	
	diffusion down concentration gradient	back e. m. f.
	or	
	electrolytic e. m. f.	capacitance fully charged
bulk matter	adhesion of parts of opposing surfaces	surfaces separated
	or	
	particulate contamination transferred mechanically	surfaces separated

rium is established, there will be an excess of charge of one sign in one phase and an excess of charge of the opposite sign in the other phase or at the interface. This gives rise to various charge separation phenomena (Table 2), some unwanted, others of commercial applicability.

TABLE 2
Examples of charge separation phenomena

Nature of Interface	
Solid–Solid	Static Electrification by Rubbing, Thermocouple, Movement of Grain Dusts through Pneumatic Systems, Discharge of Grain from Storage Silos, Paper Printing, Charge Accumulation on Synthetic Fabrics
Liquid–Liquid	EMF Developed at Liquid Junction, Dropping Mercury Electrode
Gas–Liquid	Gas Bubbling through Organic Liquids
Liquid–Solid	Electrolytic cell, Electrophoresis, Electro-osmosis, Electrification by Spraying, Fabric Spinning through Spinneret Heads, Flow of Liquids through Pipelines and Filters, Liquid Metals (Mercury) through Capillaries, Blood Flow Past Prosthetic Surfaces
Gas–Solid	Ionized Gases or Plasmas Flowing Past Surfaces, Electrostatic Precipitation
Free Surface	Unconfined Flames or Ionized Gases

Certain aspects associated with the above separation phenomena, such as thermocouple, dropping mercury electrode, electrophoresis, electro-osmosis, have been studied extensively and are reasonably well understood. Other processes dealing with streaming potential associated with flow past surfaces of relatively high conductivity liquids, such as aqueous solutions,[12,13] and in slightly conducting organic liquids (hydrocarbons) in turbulent flow through capillaries[4,5] are also reasonably well understood. Basic differences in electrical behavior exist between the latter two classes of fluids mainly because of differences in conductivity. Some typical values of conductivity for several different liquids are given in Table 3 (solids are included for comparative purposes).

A simple example will serve to illustrate pronounced differences due to conductivity. For example, consider the distance to which a charged layer on a plane surface extends into a quiescent liquid for which the potential decays to 1/e of its value at the surface. The thickness of this layer is called the Debye double layer, given by

$$\delta = (D\tau)^{1/2} \quad \text{(see Note below)}$$

where D is the mean diffusion coefficient in cm^2/sec, τ is the relaxation time in sec and equal to $\epsilon\epsilon_0/K$. K is the specific conductivity in Ω^{-1}cm^{-1}, ϵ is the dielectric constant and ϵ_0 is the free space permittivity equal to 8.85 x 10^{-14} sec/Ωcm. Values of δ for $D = 10^{-5}$ cm^2/sec for a typical high conductivity fluid such as a saline solution of $K = 10^{-3}\Omega^{-1}$cm^{-1} ($\epsilon = 80$) and a toluene solution for $K = 10^{-14}\Omega^{-1}$cm^{-1} ($\epsilon \simeq 2$) are equal to 2.7 x 10^{-7} cm and 1.33 x 10^{-2} cm, respectively. Thus, we see a shifting from microscopic to macroscopic behavior for these different conductivity materials. Materials of different conductivity, fluid mechanical parameters, geometrical changes on the rate of generation of charge in flowing

Note: The rationalized c.g.s. system of units is used in this work. The system combines the c.g.s. units for non-electrical quantities with the electrical units of ampere, volt, and ohm. The permittivity of free space $\epsilon_0 = 8.85$ x 10^{-14} sec/Ω-cm, is required as a conversion factor. The symbols used are listed in the Nomenclature.

TABLE 3
Specific conductivity and dielectric constant for several liquids and solids

Specific Conductivity ($\kappa - \Omega^{-1}cm^{-1}$)	Dielectric Constant (dimensionless)
Ethanol $1.5 \times 10^{-7} - 1.35 \times 10^{-9}$	25.7
Benzene $7.6 \times 10^{-8} - <1 \times 10^{-18}$	2.3
Toluene $<1 \times 10^{-14}$	2.4
Hexane 1×10^{-18}	1.9
Nylon 2.5×10^{-15}	3.5
Polyethylene 6.3×10^{-14}	2.3
Polytetrafluoroethylene $<10^{-15}$	2.0
Polystyrene Molding $10^{-17} - 10^{-19}$	2.5
Water (Absolute Purity) 10^{-7}	80.4

systems, and transient decay of accumulated charge in liquids are detailed in References 4, 5, 9, and 14. Close inspection of these latter works reveals that it is possible to obtain a detailed understanding of highly complex processes by solution of a generalized equation for the time-dependent transport of charge by electrical conduction, convection and diffusion [15] or by dimensional analysis.[16] Although the successful applicability of this equation has been limited to liquids, there are reasons to believe that it is also applicable to gases [15] and solids. At the earth's surface the conductivity of the atmosphere averages about $3 \times 10^{-16}\Omega^{-1}cm^{-1}$ ($\epsilon \simeq 1$) and varies between 50 and 200% of this value over long time periods. A vertical potential gradient exists which gives rise to a slight excess of positive ions over negative ions. Since the mobility of the positive ion is only about 16% smaller than that of a negative ion, the equation for charge transport formulated on the basis of equal ionic mobilities and other approximations, is met to a close approximation for gases. These differences in ionic mobilities could, perhaps, be one of the reasons why a positive discharge ignites better than a negative one, i.e., the lower positive ionic mobility is less effective in dissipating charge than negative ions.[17]

For the slightly conducting solids in Table 3, which are essentially very good insulators, electrons cannot be the charge carriers. Transport of charge can come about via ionic transport or through material transfer. The charging of textiles and quartz powder [11] has been explained using the material transfer approach. With the exception of charging of an insulator such as glass by flowing liquid mercury (no ions available and electrons cannot carry charge in mercury), little definite information exists about charging by material transfer.

Other subtleties exist in comparing electrostatic behavior among solids, liquids, and gases. Noteworthy is the "so-called" Triboelectric Series for solids, in which each substance becomes positively charged if rubbed against any substance listed following it in the series:

> ASBESTOS — GLASS — MICA — WOOL — CAT FUR — LEAD — SILK — ALUMINUM — PAPER — COTTON — WOOD, IRON — SEALING WAX — EBONITE — Ni, Cu, Ag, BRASS — SULFUR — Pt, Hg — INDIA RUBBER.

It is very important to have a clear picture of at least some of the many variables that can influence the electrostatic behavior of various processes, since this will provide the groundwork for more detailed discussions to follow. It is with this intent that we draw attention to the similarities and differences existing between the liquid, solid, and gaseous phases at this early stage.

Fundamental Principles

We assume a knowledge of basic electrostatic principles covering Coulomb's law up to Maxwell's field equations and the presence of uni-univalent ions in a dielectric continuum. A brief accounting of ionization equilibria in low-dielectric constant, low-conductivity liquids is provided in Refs. 12, 13 which substantiate the ionization assumptions. Following Gavis [7,8,15] we assume transport of flux of charge by diffusion, conduction, and convection as follows:

$$j_+ = -D_+F\nabla c_+ - \frac{D_+F^2c_+}{RT}\nabla\psi + \vec{v}Fc_+, \tag{1a}$$

$$j_- = D_-F\nabla c_- - \frac{D_-F^2c_-}{RT}\nabla\psi - \vec{v}Fc_-. \tag{1b}$$

The total flux of charge is now $j = j_+ + j_-$. Imposing charge conservation, i.e., $\partial q/\partial t = -\nabla\cdot j$, and utilizing the standard electrokinetic definitions for electrical conductivity and relaxation time,

$$K_\pm = |Z_\pm|\mu_I F c_\pm = D_\pm F^2 c_\pm/RT. \tag{2}$$

Since $|Z_\pm| = 1$,

$$\tau = \epsilon\epsilon_0/K, \tag{3}$$

and insertion of Poisson's equation,

$$\nabla^2\psi = q/\epsilon\epsilon_0, \tag{4}$$

into charge conservation equation we obtain:

$$\frac{\partial q}{\partial t} = -\nabla\cdot j = D\nabla^2 q - q/\tau + \frac{DF^2}{RT}\nabla\psi\cdot\nabla c - \vec{v}\cdot\nabla q + q\nabla\cdot\vec{v} + \frac{D'F}{RT}\{q\nabla^2\psi + \nabla\psi\cdot\nabla q\}. \tag{5}$$

In most cases involving hazard assessment, the latter two terms on the right are unimportant, i.e., $D' \simeq 0$ and the fluid may be considered incompressible ($\nabla\cdot\vec{v} = 0$) for Mach numbers less than around one. However, if we are examining gas-phase charge transport, then ionic recombination becomes important.[18,19] Eq. 5 may be modified accordingly by incorporating a recombination term ηq^2, where η is a modified recombination coefficient to allow for differences between q^2 and the usual number density of charge carriers. Also, D would now become the ambipolar diffusion coefficient.[20] Further simplification may result (1) by making an order-of-magnitude comparison of the four remaining terms in Eq. 5 in standard manner:

$$\frac{\text{Diffusive}}{\text{Convective}} \simeq \frac{Dq/L^2}{Uq/L} = D/UL = \frac{1}{ReSc},$$

$$\frac{\text{Diffusive}}{\text{Conductive}} \simeq \frac{Dq/L^2}{q/\tau} = \frac{D\tau}{L^2} = (\delta/L)^2,$$

$$\frac{\text{Convective}}{\text{Conductive}} \simeq \frac{Uq/L}{q/\tau} = \frac{U\tau}{L} = ReSc(\delta/L)^2,$$

$$\frac{\text{Conductive}}{\text{Product of Gradients}} \simeq \frac{Kq/\epsilon\epsilon_0}{K\psi/L^2} = \frac{q/\epsilon\epsilon_0}{\psi/L^2} = 1,$$

where U = characteristic flow velocity, L = characteristic length, and $\psi/L^2 \simeq q/\epsilon\epsilon_0$ from Poisson's equation; and (2) by dropping terms of low order.

An important consideration at this time is the requirement of similar charging for geometrically similar systems. The practical consequences are evident here for, if similar charging can be obtained in a laboratory setup, then one need not resort to full-scale measurements on various processes. In other words, electrostatic charging occurring in large-scale equipment may be conveniently studied on a scaled-down version of some predetermined value in the laboratory. Assuming steady state, for illustrative purposes, then imposing the requirement of similitude on the working form of Eq. 5

$$D\nabla^2 q - q/\tau - \vec{v}\cdot\nabla q + K/c\ \nabla\psi\cdot\nabla c = 0, \tag{6}$$

$$D'\nabla'^2 q' - q'/\tau' - \vec{v}\cdot\nabla' q' + K'/c'\ \nabla'\psi'\cdot\nabla' c' = 0, \tag{7}$$

where:

$$q' = \lambda_q q, \quad \vec{v}' = \lambda_v v, \quad D' = \lambda_D D, \quad \tau' = \lambda_\tau \tau, \quad L' = \lambda_L L,$$

$$K' = \lambda_K K, \quad c' = \lambda_c c, \quad \nabla' = \lambda_L \nabla, \quad \nabla'^2 = \lambda_L{}^2 \nabla^2, \quad \psi' = \lambda_\psi \psi.$$

Substituting for the primed members into Eq. 7 we obtain

$$\lambda_q\lambda_D\lambda_L{}^2 D\nabla^2 q - \frac{\lambda_q}{\lambda_\tau} q/\tau - \lambda_v\lambda_q\lambda_L \vec{v}\cdot\nabla q + \lambda_K\lambda_L{}^2\lambda_\psi\lambda_c \frac{K}{c} \nabla\psi\cdot\nabla c = 0. \tag{8}$$

Now the following equalities are necessary in order that Eq. 8 equal Eq. 6:

$$\lambda_D\lambda_q\lambda_L{}^2 = 1 \qquad \text{(a)}$$

or

$$q'\frac{D'}{L^2} = q\,D/L^2,$$

$$\lambda_q/\lambda_\tau = 1 \qquad \text{(b)}$$

or

$$q'/\tau' = q/\tau,$$

$$\lambda_v \lambda_q \lambda_L = 1 \qquad \text{(c)}$$

or

$$\frac{v'q'}{L} = \frac{vq}{L},$$

$$\lambda_K \lambda_L{}^2 \lambda_\psi \lambda_c = 1 \qquad \text{(d)}$$

or

$$K'L'^2\psi'c' = KL^2\psi c.$$

It is virtually impossible that conditions *a–d* can be met in practice. However, if we neglect *d* and thus limit ourselves to those cases previously covered on page 193, then requirements *a–c* may be stated such that true similarity will be preserved if and only if the volumetric charge transport rates by diffusion, conduction, and convection are identical for actual system and model. A further simplification is often possible, since the relaxation time may be taken as a constant provided the electrical conductivity is approximately constant (this fact was verified in Refs. 5,6,9); thus

$$D'/L'^2 = D/L^2,$$

$$v'/L' = v/L,$$

or upon multiplication by τ,

$$\delta'/L' = \delta/L, \qquad \text{(a)}$$

$$Re'Sc'\ (\delta'/L')^2 = ReSc\ (\delta/L)^2, \qquad \text{(c)}$$

where condition *c* is rewritten in familiar engineering terms, i.e., *Re* is the Reynolds number and *Sc* the Schmidt number.

A simple example might serve to illustrate imposition of the requirements *a* and *c*. Let us say we are interested in studying the charging process in a model of scale factor 1/20 actual size, i.e., let $L' = L/20$, and treat the dielectric constant ϵ and the diffusion coefficient *D* as constants (this is true to a close approximation: note ϵ in Table 3 and see Ref. 12). Then in order that

$$\frac{1}{K'(1/400L^2)} = \frac{1}{KL^2},$$

K' must be increased by a factor of 400. This is readily accomplished for slightly conducting hydrocarbon fluids by addition of ionizing solutes. Inserting condition *a* into *c*, one therefore requires equality for the product of Reynolds number times Schmidt number, i.e., the Peclet number. Since the Schmidt number will remain unchanged at least for the above case, then requirement *c* reduces simply to equality of the Reynolds numbers. Thus, for $L' = L/20$, Re' will remain equal to Re by simply increasing the characteristic flow velocity for the test model twenty-fold, $U' = 20U$. Adjustments in ρ'/μ' may also be used to maintain fixed Reynolds numbers; however, care should be taken so that changes in ρ'/μ' will not alter K' from its value specified under a.

Based on the above example, it appears relatively easy to preserve charge transport similarity for a model of a large-scale system. One need only make certain (1) that the ratio of the Debye double layer thickness to characteristic length, δ/L, remains fixed for system and model by changing the electrical conductivity; and (2) that the Peclet number also remains fixed by conveniently adjusting the characteristic flow velocity. Returning to conditions a, b, c we note that conditions a and c resulted from the equality of charge density. That can only be true in rare cases since q itself is a function of many variables (see page 198). Thus, in small test models it is apparent that only partial similarity can be preserved. Or, alternatively, errors may result if small-scale test data are to be used to predict charging behavior in large-scale systems.

Gibson and Lloyd [21] were the first to show experimentally on a large-scale test setup that the theoretical derivations of Koszman and Gavis,[4-6] Gibbings and Hignett,[22] Hignett [23] and Gavis [7,8] for turbulent flow through capillaries and small tubes require further modifications before they could be used to predict accurately electrification in large-scale systems.

There is one additional requirement concerning charging similarity: an examination of the nature of the boundary conditions. That is, complete similarity, in addition to the other cited requirements, also requires similar boundary conditions.

In the following section the nature of the boundary condition at a liquid-solid interface is considered in some detail.

Boundary Conditions for Charged Interface

The amount of charge crossing an interface may be given by analogy with classical heat and mass transfer theory as follows:

$$Q' = hAF\Delta C = hA\Delta q, \tag{9}$$

where

$\Delta C = c_+ - c_-$, the concentration driving force, eq/cc,

Q' = rate of charge transfer across interface, coul/sec,

h = charge transfer coefficient, cm/sec,

and A and F are standard quantities. Strictly speaking, Eq. 9 is the definition of the charge transfer coefficient. Let us limit ourselves to flow in conduits and charge transfer occurring within the control volume sketched in Fig. 1. Furthermore, if we limit ourselves to charging at the control volume inlet (i.e., Plane 1), although we could specify conditions at Plane 2, or a mean value, the charge crossing the interface is given by:

$$Q' = h\pi dL\,(q_{b1} - q_{o1}).$$

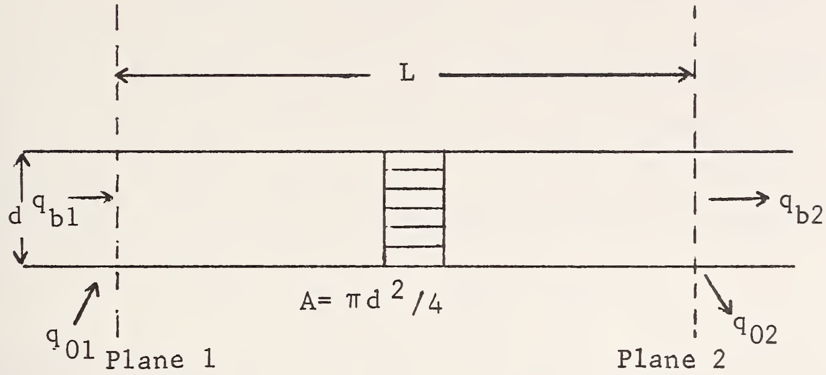

FIG. 1. Sketch of control volume for charge transfer

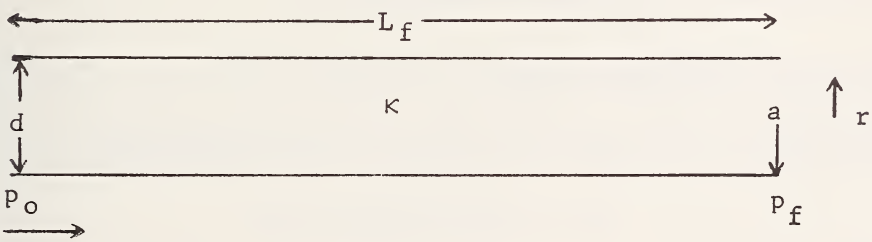

FIG. 1A. Sketch of simplified model of porous filter

Equating Q' to the total charge flow from the fluid to the tube wall over the length L, we obtain

$$h\pi dL\,(q_{b1}-q_{o1}) = \int_o^L \int_o^{2\pi} -D\frac{\partial q}{\partial r}\bigg|_{r=d/2}\left(\frac{d}{2}\right) d\theta dz.$$

Defining the dimensionless quantities,

$$q_r \equiv \frac{q-q_{o1}}{q_{b1}-q_{o1}}\; z_r \equiv z/d\; r_r \equiv r/d,$$

and inserting into the above equation gives:

$$h/D = \frac{1}{2\pi L}\int_o^{L/d}\int_o^{2\pi} -\left(\frac{\partial q}{\partial r_r}\right)_{r_r=1/2} d\theta dz,$$

or in terms of the Nusselt number,

$$Nu = \frac{hd}{D} = \frac{1}{2\pi L/d}\int_o^{L/d}\int_o^{2\pi} -\left(\frac{\partial q_r}{\partial r_r}\right)_{r_r=1/2} d\theta dz.$$

Now the solution of the charge transport equation may be denoted symbolically as

$$q_r = q_r(r_r, \theta_r, z_r, \frac{\delta}{L}, \frac{U\tau}{L}, \psi_r).$$

The Nusselt number is, therefore, a function of

$$Nu = Nu\left(\frac{\delta}{L}, \frac{U\tau}{L}, \psi_r, \frac{L}{d}\right).$$

Or if we rewrite $U\tau/L$ as $ReSc\,(\delta/L)^2$, then Nu is given symbolically by

$$Nu = Nu(Re, Sc, \delta/L, \psi_r, L/d)$$

or as

$$Nu = ARe^{\alpha}Sc^{\beta}(\delta/L)^{\sigma}\psi_r{}^{\phi}(L/d)^{\omega}, \tag{10}$$

where A is a constant and α–ω are the powers to which the dimensionless groups are raised.

For processes dealing with fully developed flows, the entrance region correction term, $(L/d)^{\omega}$, is unimportant; whereas, for cases in which ψ is close to its reference value, ψ_o, then $\psi^{\phi}{}_r$ is generally unimportant. Thus, we are left with the simplified form for the Nusselt number,

$$Nu = ARe^{\alpha}Sc^{\beta}(\delta/L)^{\sigma}.$$

In their initial studies which introduced the use of mass transfer Nusselt number to represent charge transfer in turbulent flow through capillaries, Koszman and Gavis [4,5] assumed that the ratio of the double layer thickness to characteristic length, δ/L, i.e., $\sigma = 0$ in Eq. 10, is unimportant. In other words, this assumption implies that the presence of a charge gradient or an electrically charged double layer at the liquid-solid interface does not influence the charge transfer rate across the interface. This reasoning does not follow from the present generalized approach. Also for the extreme cases δ/L large, σ small; δ/L large, σ large; δ/L small, σ small; δ/L small, σ large; only the latter value of $(\delta/L)^\sigma$ is negligible for essentially all practical cases.

The important question to resolve here is: in using heat or mass transfer correlations to describe charge transfer, how should one account for the added term δ/L? If we take $\beta = 1$, $\sigma = 2$ and rewrite $Sc(\delta/L)^2$ as

$$Sc(\delta/L^2 = \nu/(L^2/\tau) = \nu/(L^2K/\epsilon\epsilon_o), \tag{11}$$

then one may interpret $\nu/(L^2K/\epsilon\epsilon_o)$ as the ratio of diffusivity of momentum to an electrokinetic diffusivity. It appears, therefore, that this nondimensional number may be an electrokinetic analogue of the mass transfer Schmidt number. Thus, as a first approximation one would expect to substitute $Sc(\delta/L)^2$ for Sc in mass transfer correlations for the Nusselt number and carry over these correlations to describe charge transfer in geometrically similar systems.

Further evidence in support of the above arguments is provided in the following sections and in Appendix A. However, a brief accounting is given here for emphasis:

1) Koszman and Gavis's [5,6] dimensionless number $G = d^2/Re^{7/4}\tau\nu$ is in terms of the present study, equal to

$$\frac{1}{Re^{7/4}Sc(\delta/d)^2} = d^2/Re^{7/4}\tau\nu.$$

2) Wagner and Gavis's [9] dimensionless number $v_p\tau_o/d_p$ for flow through microporous media is equal to $Re_{d_p}Sc(\delta/d_p)^2$ where the d_p denotes the pore diameter. Actually, $Re_{d_p}Sc(\delta/d_p)^2$ in the context of this discussion may be interpreted as an electrokinetic Peclet number.

Dimensional Analysis

Two approaches to a dimensional analysis have appeared in the literature. The first is that of Gavis [15] who nondimensionalized the charge transport equation to arrive at the following two representations (Ref. 7 treats non-linear equation):

$$\frac{\partial q_r}{\partial t_r} = \left(\frac{\delta}{L}\right)^2 \nabla^2{}_r q_r - q_r - \left(\frac{\vec{v}\tau}{L}\right) \vec{v}_r \cdot \nabla_r q_r, \tag{12}$$

where

$$t_r = t/\tau,\ q_r = q/q_o,\ \nabla^2{}_r = L^2\nabla^2,\ \vec{v}_r = \vec{v}/U, \text{ and } \nabla_r = L\nabla,$$

or

$$\frac{\partial q_r}{\partial t_r} = \frac{1}{ReSc} \nabla^2{}_r q_r - \frac{1}{ReSc(\delta/L)^2} q_r - \vec{v}_r \cdot \nabla q_r, \tag{13}$$

where

$$t_r = t/(L/U).$$

The second approach was developed by Gibbings and Hignett [22] who considered electrical and thermal effects as well as the nature of the boundary.

Earlier, the author met little success in applying the Gibbings and Hignett approach to correlate current data generated during flow of a low-conductivity hydrocarbon through microporous media. Perhaps this was due to nomenclature difficulties previously mentioned in the introduction. An unpublished approach of Wagner,[16] using the classical Buckingham π method, successfully correlated this data. This approach will be considered in depth as a separate subsection, "Flow through Porous Media."

Application of Principles

Three problem areas involving flow of slightly conducting liquid hydrocarbons are considered: turbulent flow through capillaries and pipes, flow through porous media, and laminar flow through capillaries. In some cases only the final result of the application of principles is presented since the original studies can always be referred to.

Turbulent Flow Through Capillaries and Pipes

Earlier Koszman and Gavis [4] presented a detailed review and critique of existing literature. Prior to their study, the theories were based on the classical double layer approach and were deficient or lacking in the following key points:

(1) Classical theories do not provide the proper experimentally observed charge generation rate (i.e., the measured current) vs conductivity/flow dependence, which exhibits a maximum, dependent on both conductivity and flow velocity (Fig. 2). The proper length dependence is also not provided. Furthermore, the streaming potential is assumed to be a fundamental parameter; however, it was earlier observed to have a functional dependence on the Reynolds number.

(2) Modification of the classical theory led either to an equation which gave a parametric dependence for the generated current that was contrary to observation, or led to a reasonable prediction of the current/length-velocity dependence but required introduction of a wall current that was of an unspecified origin.

These defects provide some justification for the charge density viewpoint utilized herein.

Koszman and Gavis [4,5] view the charging process as illustrated in Fig. 3. The rate limiting process at the tube wall was assumed to be due to concentration polarization (i.e., ohmic and activation polarizations are small with respect to concentration polarization). Here the thickness of the layer near the wall, where the concentration changes from c_o in the liquid bulk to c_s at the surface, is known as the diffusion layer thickness, λ. By analogy with heat and mass transfer

$$\lambda = d/Nu,$$

where d is the tube diameter and Nu is the Nusselt number. For fluids of high

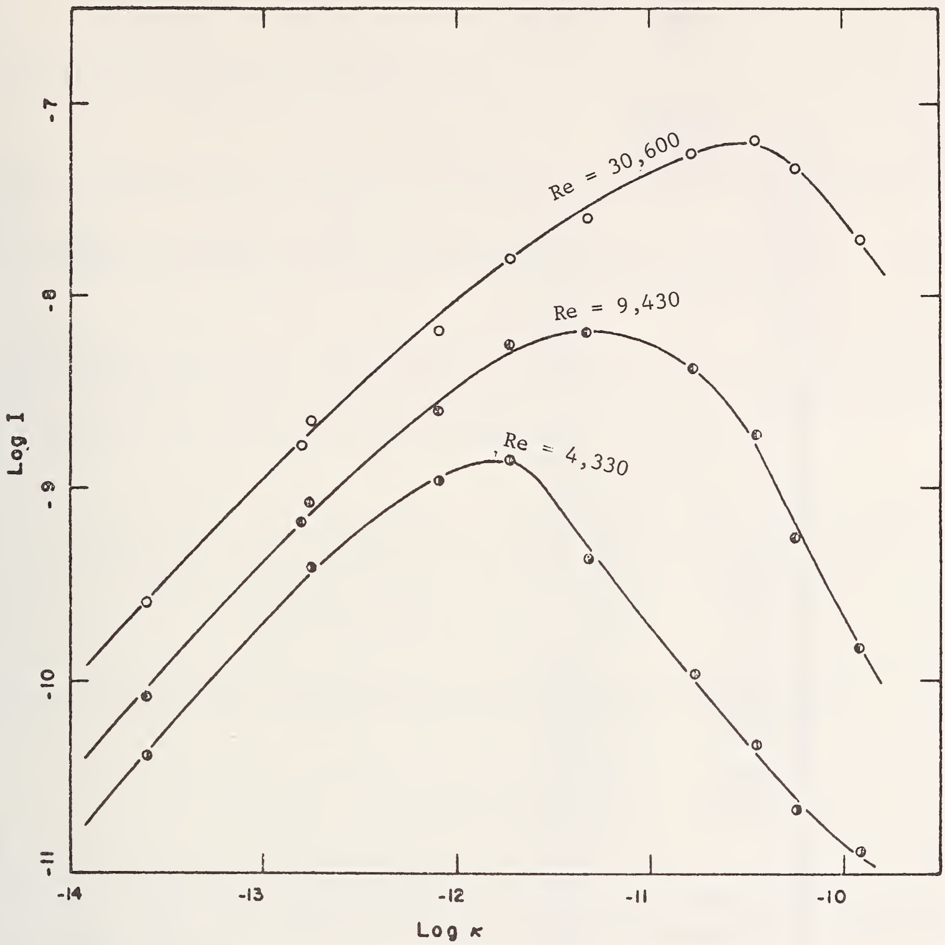

FIG. 2. Charging current dependence on conductivity for turbulent flow through platinum capillary —$L/d = 168$.

Schmidt number Deissler's[24] correlation, based on assumption of a constant flux boundary condition for turbulent flow through tubes gives for Nu

$$Nu = 0.022 Re^{7/8} Sc^{1/4}. \tag{14}$$

Now the surface current flux, j_s, in the absence of an electric field was taken to be

$$j_s = -\frac{DF}{\lambda n_+}(1 - c_s/c_o) = \text{Const.},$$

where n_+ is the transference number for positive ions. This was equated to the gradient at the tube wall (a rigorous derivation of the boundary conditions is given by Gavis[15]) such that

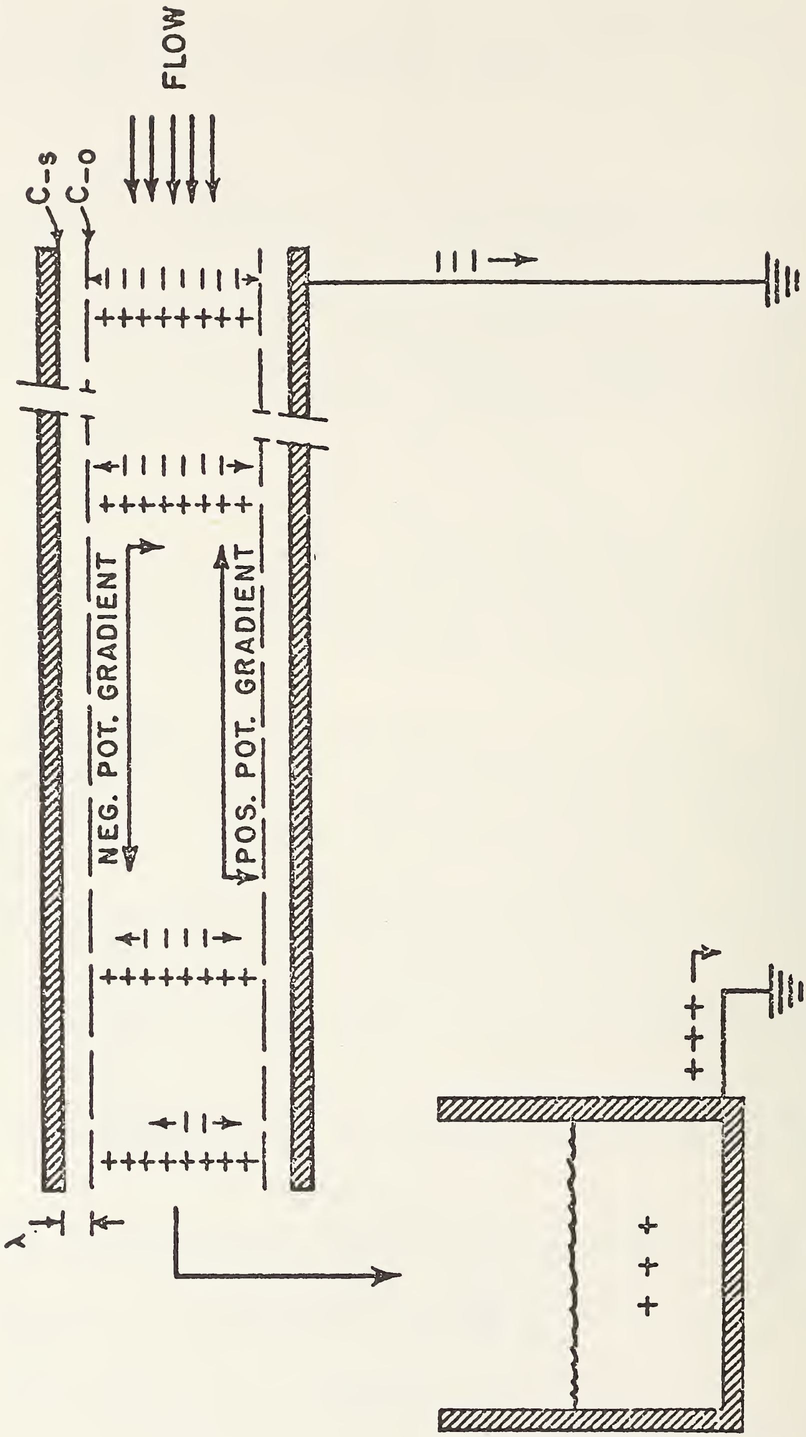

FIG. 3. Schematic diagram of generation of the charging current by liquid flowing through a tube.

$$D\left.\frac{dq}{dr}\right|_{r=a} = \frac{DF}{\lambda n_+}(1-c_s/c_o) = \frac{KRT}{2n_+Fd}Nu\ (1-c_s/c_o). \tag{15}$$

The remaining boundary conditions were

$$q|_{o,r} = 0, \tag{16}$$

i.e., the fluid enters the tube inlet uncharged, and symmetry about the tube axis,

$$\left.\frac{\partial q}{\partial r}\right|_{r=o} = 0 \qquad \text{for } x \geq 0. \tag{17}$$

The linearized form of the charge transport equation (Eq. 12 or 13) subject to above boundary conditions (Eqs. 15–17) requires a numerical approach for solution since D and v are non-simple functions of r. A closed form solution was given for the extreme case of D and v independent of r as

$$q = \frac{F(1-c_s/c_o)}{\lambda n_+}\,\delta\left\{\frac{I_o\left(\frac{r/a}{\delta/a}\right)}{I_1\left(\frac{1}{\delta/a}\right)}\right\} - \frac{2a}{\delta}\sum_{n=o}^{\infty}\frac{J_o\left(\frac{\alpha_n r}{a}\right)\exp-\left(\frac{1}{v\tau}+\frac{\alpha^2{}_n D}{a^2 v}\right)x}{(\alpha^2{}_n - a^2/\alpha^2)J_o(\alpha_n)}$$

where α_n is the nth zero of the first order Bessel function of the first kind,

$$J_1\ (\alpha_o) = 0,$$

$$J_o\ (\alpha_o) = 1,$$

and I_o, I_1 are the modified Bessel functions.

Experimentally, one cannot measure q directly; however, by integrating q over the product of the cross-sectional area times flow velocity, we obtain an analytical value for the current

$$I = 2\pi\int_o^a rq(L,r)\,v(r)\,dr. \tag{18}$$

Substitution of q into Eq. 18 and performing the integration gives:

$$I = \frac{\pi\epsilon\epsilon_o RT\bar{v}}{2n_+F}\,(0.022Re^{7/8}Sc^{1/4})\,(1-c_s/c_o)\,(1-e^{-L/\bar{v}\tau}). \tag{19}$$

Eq. 19 may also be obtained for the assumption that the initial charge distribution is approximately uniform across the tube. This occurs in practice when $\delta \gtrsim d$, i.e., for very low conductivity fluids and in regions unaffected by development of charged boundary layers.

For cases in which the charge distribution is confined to the wall region, and thus within the laminar subzone, it can be shown that

$$I = 4.42 \times 10^{-4} \left\{ \frac{\pi KRT}{n_+ F d^2 D} (D\tau)^{3/2} Re^{21/8} Sc^{1/4} \nu \right\} (1 - c_s/c_o). \tag{20}$$

In practice this confined charge distribution is approximated by high-conductivity hydrocarbon fluids.

For cases not represented by Eqs. 19 and 20, an inspectional analysis of the governing equations was performed to deduce the functional relationship given by

$$I / \frac{(1 - e^{-L/v\tau})}{I_\infty} = G \left\{ \frac{d^2}{Re^{7/4}\tau\nu}, Re, Sc \right\}, \tag{21}$$

where $G \rightarrow 1$ when $d^2/Re^{7/4}\tau\nu$ is small, and $G \rightarrow 0.0395\ (d^2/Re^{7/4}\tau\nu)^{-1/2} Re^{-1/8} Sc^{-1/2}$ when $d^2/Re^{7/4}\tau\nu$ is large and where I_∞ is the limiting current when $L/v\tau \gg 1$.

The experimental data given in Fig. 4, in which

$$log\ \frac{I}{\epsilon\epsilon_o \bar{v}^{15/8} d^{7/8} (1 - e^{-L/\bar{v}\tau})}$$

is plotted vs $d^2/Re^{7/4}\tau\nu$, substantiated the general approach of Koszman and Gavis over a wide range of system parameters. However, the high conductivity approximate solution, Eq. 20, as given by lines D and E in Fig. 4, is at best a rough approximation of the observed behavior for $d^2/Re^{7/4}\tau\nu \gtrsim 10^{-5}$. The shift in the plotted ordinate from a value of around zero for stainless steel tubes to a value of around 0.7 for platinum tubes was suggested by Koszman and Gavis as being due to surface roughness not accounted for in their theory. This suggestion does not appear to be valid in light of Gibson and Lloyd's study [21] which addressed the surface roughness postulate. They compared internal surfaces of 0.32 cm and 2.88 cm diameter tubes for roughness and found the former to be rougher than the latter. However, the experimental value of $I_\infty/v^{15/8}d^{7/8}$ obtained with the latter was greater than that obtained for the 0.32 cm tube, whose value for $I_\infty/v^{15/8}d^{7/8}$ was close to the value predicted by Koszman and Gavis's equation.

One can speculate on a number of other reasons for the differences noted between the platinum and the stainless steel tubes. Certainly the unusual electrochemical and/or catalytic activity of platinum [24] vs other metals such as those present in stainless steel might be expected to enter the picture. However, the suggested reason(s) must preserve the overall features of the Koszman and Gavis approach since the A and B curves in Fig. 4 are merely shifted in the value of the ordinate. The simplest way to view this is to say that the assumption $(1 - c_s/c_o) \simeq 1$, i.e., $c_s/c_o \ll 1$, may not be valid. This may be accounted for by arbitrarily setting $1 - c_s/c_o = 1$ for stainless steel; then a value of $1 - c_s/c_o$ can easily be determined for platinum that will transpose curve A to curve B in Fig. 4.

Some caution should be exercised in applying the data in Fig. 4 to all systems, for the following reasons:

1) The plotting variable for the ordinate is not dimensionless. Compare with Eq. 19 and note the missing Sc number and kinematic viscosity term from the Reynolds number. Thus,

$$Sc^{1/4} \frac{1}{\nu^{7/8}} = \frac{1}{D^{1/4}\nu^{5/8}} \text{ is the omitted term.}$$

2) For large-scale systems, the empirical correlation of Gibson and Lloyd [21] for infinitely long pipes,

$$I_\infty = K_5 d^{-1 \cdot 8} v^{1 \cdot 45 + 0 \cdot 01\, d}\, e^{0 \cdot 4\, log\, d\, log\, v}$$

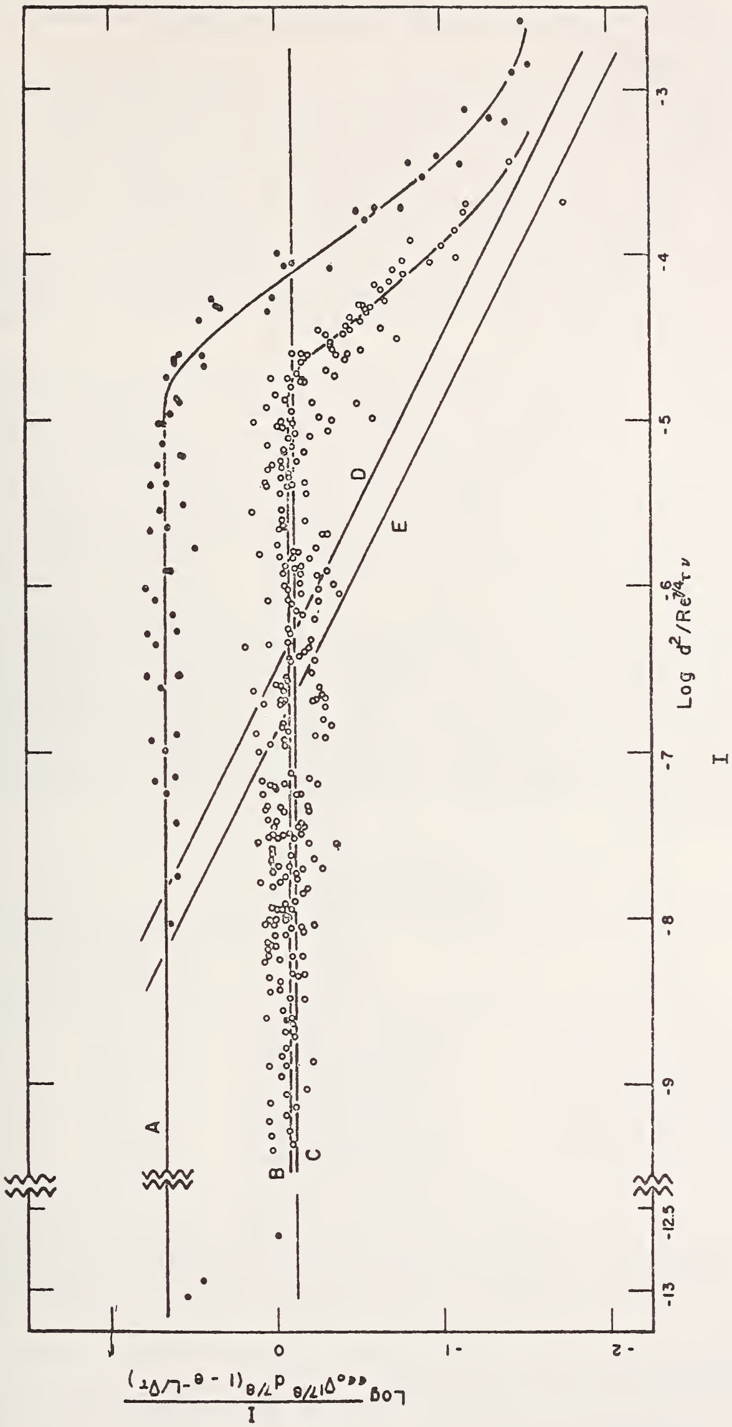

Fig. 4. Plot of log $I/\epsilon\epsilon_0 v^{15/8} d^{7/8} (1 - e^{-L/\bar{v}\tau})$ against log $d^2/Re^{7/4}\tau\nu$ for all of the data taken with platinum and stainless steel tubes.

A — Platinum Tube
B — Stainless steel tubes
C — Low κ theory, Eq. 19
D — High κ theory, for $Re = 2100$, Eq. 20
E — High κ theory, for $Re = 45{,}000$, Eq. 20

where $K_5 = (2.42 \pm 0.1) \times 10^{-11}$, should be used to calculate the current.

Flow Through Porous Media

The study by Bruinzeel et al.[26] appears to be one of the first published reports illustrating the potentially serious nature of charging in filters during low temperature refueling of aircraft. High electric field strengths (5,000 V/cm and up)* were measured in the vapor space of an aircraft tip tank, while discharges were observed during normal refueling rates. The following test highlights were obtained using glass fiber and pleated paper filters, each with water separator elements: (1) there seems to be little difference in the charging behavior of new and old type elements, as well as no gross differences in charging between the two filter types; (2) simultaneous flow of nitrogen and fuel through a filter does not affect the charging characteristics.

A recent study by the Coordinating Research Council (CRC) [27] using the filtration equipment supplying J. F. Kennedy Airport, N. Y., showed: (1) fuel characteristics have the major effect on filter charging characteristics; (2) Teflon-coated screen type separators charge less than pleated paper separators.

Other investigators who have examined charging in filters** in some length include Wagner and Gavis [9] and Leonard and Carhart.[28] Additional reports emphasizing practical electrostatic aspects should soon be available from CRC.

The study by Wagner and Gavis involved a small laboratory setup to measure the rate of charge generation through a single filter type (cellulose triacetate Millipore filters) but of a wide range of filter characteristics (Table 4) and flow conditions. Typical current-velocity-conductivity data similar to Fig. 2 were obtained. By employing a nondimensional form of the charge transport equation (simplified form of Eq. 5 in this report) and judicious reasoning, one could reduce this type of data to the dimensionless plot in Fig. 5.[9] Because it is difficult to visualize realistically the latter point, an alternative approach is presented in the following paragraphs.

TABLE 4
Filter characteristics

Filter type	Pore diameter	Filter thickness	Filter thickness to pore diameter ratio	Porosity
AA	$8.00 \pm 0.50 \times 10^{-5}$cm	$1.50 \pm 0.10 \times 10^{-2}$cm	187	82%
DA	$6.50 \pm 0.30 \times 10^{-5}$cm	$1.50 \pm 0.10 \times 10^{-2}$cm	231	81%
HA	$4.50 \pm 0.20 \times 10^{-5}$cm	$1.50 \pm 0.10 \times 10^{-2}$cm	333	79%
TW	$4.50 \pm 0.20 \times 10^{-5}$cm	$1.00 \pm 0.10 \times 10^{-2}$cm	450	43%
GS	$2.20 \pm 0.20 \times 10^{-5}$cm	$1.35 \pm 0.10 \times 10^{-2}$cm	615	75%
VC	$1.00 \pm 0.08 \times 10^{-5}$cm	$1.30 \pm 0.10 \times 10^{-2}$cm	1,300	74%
VM	$5.00 \pm 0.03 \times 10^{-6}$cm	$1.30 \pm 0.10 \times 10^{-2}$cm	3,200	72%

Employment of the Buckingham π theorem provides a well known, systematic technique for obtaining dimensionless groups useful in data correlation. Here the matrix notation approach discussed by Langhaar [29] with the measured current,

* Homogeneous values exceeding around 4,000 V/cm produce local values as high as 30,000 V/cm, the breakdown potential for air ionization.

** Here a filter is one specific type of a porous material. The latter may be defined as a solid that contains a large number of holes (often referred to as pores) usually interconnected and distributed randomly throughout its volume.

FIG. 5. Dimensionless charging current data for flow of hydrocarbon liquid through filters.

I_m, selected as the dependent variable in the π analysis is adopted along with MLTQ (mass, length, time, charge) systems of dimensions. Inspection of Eqs. 2–5, and referring to Reference 29 allows one to cast the measured current in the matrix notation (temperature and the ionic diffusivity are treated as constants) given in Table 5.

TABLE 5
Charge transport matrix

	K_1 I_m	K_2 v_p	K_3 ρ	K_4 L_p	K_5 A_v	K_6 d_p	K_7 Fc°	K_8 τ_o	K_9 μ
M	0	0	1	0	0	0	0	0	1
L	0	1	−3	1	2	1	−3	0	−1
T	−1	−1	0	0	0	0	0	1	−1
Q	1	0	0	0	0	0	1	0	0

Following Langhaar's suggested approach, the matrix in Table 5 can be reduced to the following dimensionless groups:

$$\pi_{1p} = \frac{I_m \tau_o / d_p{}^3}{Fc^\circ}, \tag{22}$$

$$\pi_{2p} = v_p \tau_o / d_p = Re_{d_p} Sc(\delta/d_p)^2,^* \tag{23}$$

$$\pi_{3p} = d_p{}^2/\nu\tau_o, \tag{24}$$

$$\pi_{4p} = L_p/d_p, \text{ and} \tag{25}$$

$$\pi_{5p} = A_v/d_p{}^2. \tag{26}$$

According to the π theorem a functional relationship, such as

$$\pi_{1p} = Cf\,\{\pi_{2p}, \pi_{3p}, \pi_{4p}, \pi_{5p}\},$$

exists between the π_{ip}'s where C is an arbitrary constant. It is often possible to express f {above} as a product of the dimensionless groups each raised to an arbitrary power such that

$$\pi_{1p} = C_1 \pi_{2p}{}^{b2} \pi_{3p}{}^{b3} \pi_{4p}{}^{b4} \pi_{5p}{}^{b5},$$

where C_1 is another constant.

Returning to Fig. 5, we see that $\dfrac{I_m \tau_o / d_p A_v}{Fc^\circ}$ is merely π_{1p}/π_{5p} and $v_p \tau_o / d_p$ is π_{2p}.

It appears that only three of the five π groups were necessary to correlate the data; π_{3p} and π_{4p} do not appear explicitly. However, π_{3p} appears implicitly in π_{2p} when the latter is written as $Re_{dp}(\nu\tau_o/d_p{}^2)$. Total absence of π_{4p} means that the current is independent of L_p/d_p. This follows readily since L_p/d_p is very large (see Table 4) and thus hydrodynamic entrance region effects are unimportant.

There are two ranges of π_{2p} for which different charging behavior is exhibited in Fig. 5. For the range $5 \times 10^3 < \pi_{2p} < 2.5 \times 10^7$,**

* $Sc(\delta/d_p)^2$ is actually $\nu\tau_o/d_p{}^2$.
** Current was always negative except when erratic behavior due to filter clogging occurred; positive currents were also obtained in the latter.

$$\frac{I_m \tau_o / d_p A_v}{Fc^\circ} = 2 \times 10^{-4} \{Re_{d_p} Sc(\delta/d_p)^2\}^{0.75}, \tag{27}$$

while for the range $6 \times 10^2 < \pi_{2p} < 5 \times 10^3$, the current* dependence is more complicated and cannot be described as simply.

Each of the π_{1p} to π_{5p} groups has a physical significance which may be interpreted as follows:

π_{1p} is the ratio of a dynamic charge density to the original total ionic concentration expressed in charge units.

π_{2p} is the ratio of a characteristic electrical length, which may be termed the charging length, to the pore diameter.

π_{3p} is the square of the ratio of the pore diameter to another characteristic electrical length.

π_{4p} is the ratio of effective pore length to pore diameter.

π_{5p} is the ratio of effective filter void area to the square of the pore diameter.

There are alternate ways of interpreting the groups. For example: (1) Writing π_{1p} as $I_m/(d_p^3 Fc^\circ/\tau_o)$, one may interpret the group $I_m/(d_p^3 Fc^\circ/\tau_o)$ as the ratio of the measured electrical current to a current of ions at their original concentration; (2) Writing π_{2p} as $v_p/(d_p/\tau_o)$ and multiplying the numerator and denominator by q, one may interpret the group $v_p q/(d_p/\tau_o) q$ as the ratio of charge transported by convection to charge transported by conduction; (3) Writing π_{3p} as $\nu/(d_p^2/\tau_o)$, one may interpret it as the ratio of the diffusivity of momentum to an electrokinetic diffusivity. It is, therefore, an electrokinetic analogue of the mass transfer Schmidt number.

Other possible groups which are products of the groups already obtained, may be formed if other choices of the k's are used. The new groups, entirely equivalent to the old ones, may also be assigned physical significance. The groups π_{1p}–π_{5p}, already described, proved to be most convenient for this investigation. Therefore the groups obtained from other values of the k's are not illustrated.

A theoretical explanation of the charging process was offered earlier [16]; however, a number of uncertainties bar its general applicability. These are pointed out in Appendix A with hope that any possible errors contained therein may lead to future corrections or to the introduction of an entirely new theoretical approach.

Leonard and Carhart's study [28] on various filter materials (fiberglass—bonded and baked, nylon, Kel-F, dacron and ordinary glass wool) appears to be in general agreement with previously observed electrostatic behavior. For example, their data show the typical current increase with conductivity, the passing through a maximum and subsequent decrease with increasing conductivity. Because of unknown filter characteristics such as surface area, effective pore diameter, etc., their data could not be cast into the dimensionless parameters plotted in Fig. 5 to check out the adequacy of this correlation for other filter types.

Leonard and Carhart's observation that the sign of the charge on a fuel may be controlled by controlling the nature of the filter surface led to suggestion of three new approaches for practical control of static electricity. One of their approaches was tested successfully; they divided fuel flow into two separate streams each containing filters (one that acquired a positive charge, the other negative) and carefully controlled the flow through each, thus leading to virtually no net charge on a receiving tank. This novel approach seems to offer considerable potential for practical control of static electricity in liquids. It is recognized that it might be

* Both positive and negative currents were measured; in some cases current polarity shifted during the same run but preserved the same magnitude of the current.

difficult to have precise flow control under all field conditions; however, even here it might be used to augment existing standard control techniques involving use of additives to increase electrical conductivity, charge relaxation techniques, and corona-type static charge reducers.

Laminar Charge Generation of Low-Conductivity Hydrocarbons in Capillaries

There are apparently no published electrostatic data involving laminar charging of low-conductivity fluids in single capillaries. This is understandable in a practical sense, since fluids are nearly always transported in pipelines in the turbulent flow regime for economic reasons. Thus, there is limited practical incentive to examine laminar charge generation. Perhaps another reason for lack of data is that measured currents will be even lower than in the turbulent case and, consequently, it would be more difficult to obtain reproducible data. However, from a fundamental viewpoint such data are equally important.

The unpublished data of Wagner (Fig. 6) show the typical current increase—maximum value—decrease with increasing conductivity exhibited for both turbulent flow and flow through porous media. This similarity seems to imply that at least one of the earlier approaches might readily predict or correlate this data. An expenditure of some effort along these lines did not yield fruition. One important reason for lack of success seems to be implicit in the data in Fig. 6 for $K \lesssim 3 \times 10^{-13} \Omega^{-1} \mathrm{cm}^{-1}$. Here $I \alpha v^{0.5}$ suggests a possible entrance region problem since the Nusselt number for mass transfer over a flat plate has the same velocity dependence, i.e., $Nu = CRe^{1/2}Sc^{1/3}$. This idea is explored in some detail in the following paragraphs.

Following Levich [30] one may divide the capillary into three principal regions: (1) Region 1—velocity and charge profiles developing; (2) Region 2—velocity profile developed, charge profile still developing, or vice versa; and (3) Region 3—both velocity and charge profiles are fully developed as, for example, in an infinitely long tube. Tube curvature may be ignored in regions where velocity boundary layer and charge boundary layer thickness are small with respect to the tube diameter. This may now be treated as charge transport on a flat plate as sketched in Fig. 7, where δ_v is the velocity boundary layer thickness, U is the free stream flow velocity, Δ is the thickness of the charge boundary layer, q_∞ is the free stream charge density, y is distance off plate, and x is distance along the plate (the case $\Delta > \delta_v$ can also be treated; however, it is somewhat more difficult). Writing Eq. 12 in boundary layer form,

$$u \frac{\partial q}{\partial x} + v \frac{\partial q}{\partial y} = D \frac{\partial^2 q}{\partial y^2} - q/\tau, \tag{28}$$

and integrating from 0 to Δ, subject to boundary conditions

$$v = 0 \text{ at } y = 0,$$

$$\begin{cases} v = -\displaystyle\int_0^\Delta \frac{\partial u}{\partial x}\, dy & \text{at } y = \Delta, \\ q = q_o & \end{cases}$$

we obtain:

$$\frac{\partial}{\partial x} \int_0^\Delta u(q - q_\infty)\, dy = -D \left.\frac{\partial q}{\partial y}\right|_0 - \frac{1}{\tau} \int_0^\Delta q dy. \tag{29}$$

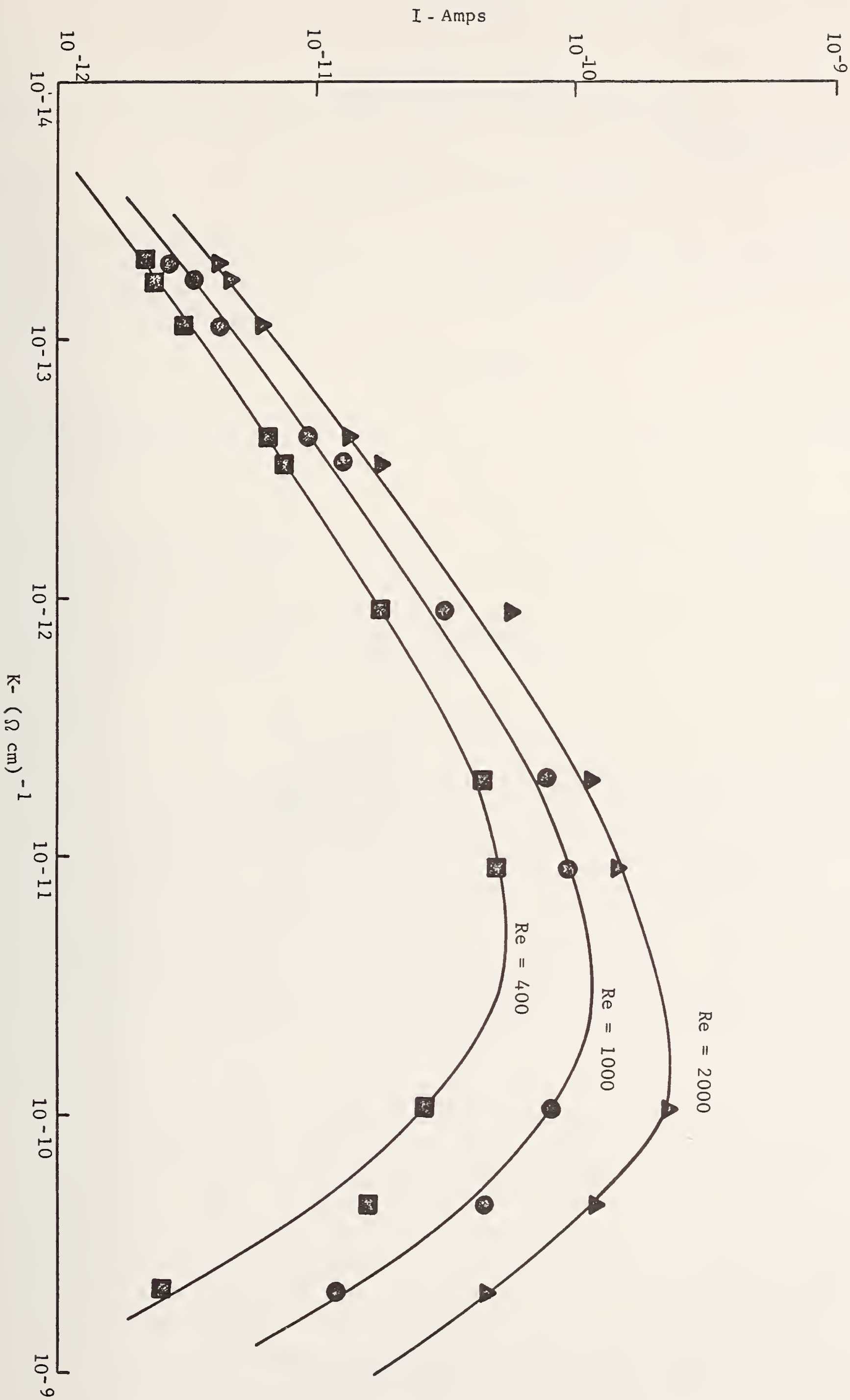

FIG. 6. Charging current dependence on conductivity for laminar flow of heptane through capillary $L/d = 600$. (unpublished data of Wagner)

Defining the local charge transfer coefficient by

$$h = -\frac{D}{q_w - q_\infty}\left(\frac{\partial q}{\partial y}\right)_{y=0} \tag{30}$$

and assuming the following simplified velocity and charge profiles for a constant wall charge density,

$$u/U = 1.5\, y/\delta_v - 1/2\ (y/\delta_v)^3, \tag{31}$$

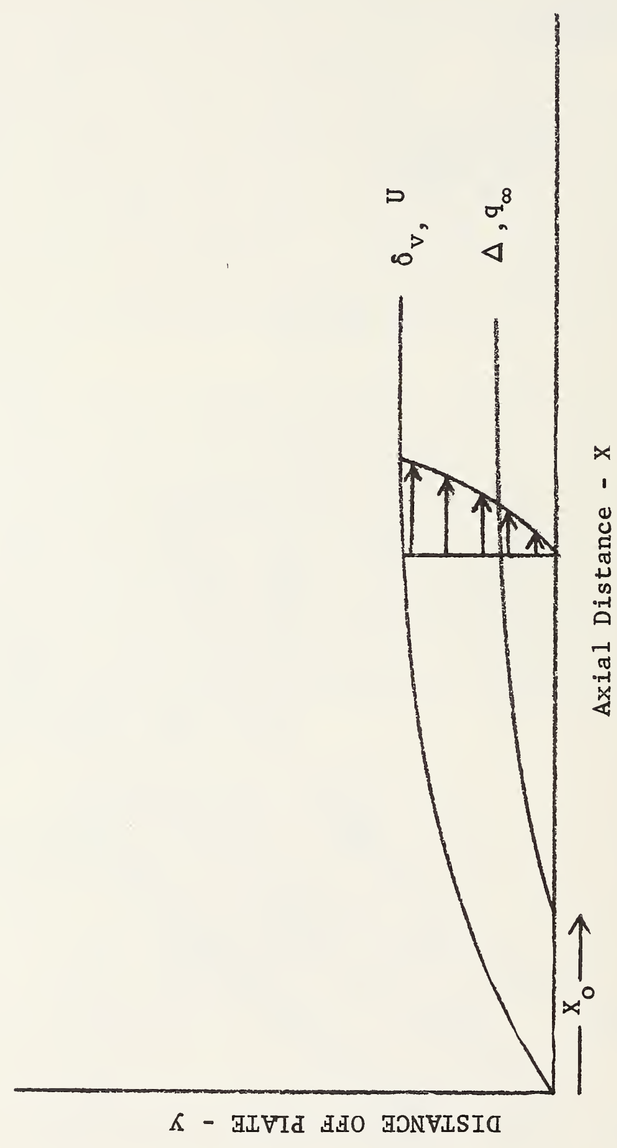

FIG. 7. Sketch of charge transport on a flat plate.

$$\text{and } \frac{q - q_\infty}{q_w - q_\infty} = 1 - 1.5\, y/\Delta + \frac{1}{2}\,(y/\Delta)^3, \tag{32}$$

it can be shown from Eq. 29 for high Schmidt number fluids that

$$\frac{\Delta}{\delta_v} = \frac{4}{5}\left\{\frac{10}{3}\cdot\frac{1}{U\tau}\left(\frac{q_\infty}{q_\infty - q_w}\right) - \frac{3}{8}\right\}\left(x - \left(\frac{x_o}{x}\right)^{1/4} x_o\right). \tag{33}$$

For our case the starting length $x_o = 0$, $x = L$, and q_w may be neglected with respect to q_∞, assuming that the electrochemical discharge process at the surface is rapid. Furthermore, if we assume that the analysis is valid only if $\Delta/\delta_v \lesssim 1/10$, then for overall validity,

$$U\tau/L \gtrsim 50/3,$$

Substituting typical values of $\tau = 1$ sec and $U = 200$ cm/sec into the inequality, we obtain:

$$L \lesssim 12 \text{ cm}.$$

Since the capillary length was 9.3 cm, the charge transport entrance region lasts the entire length of the capillary even though the velocity profile is fully developed for $L/D \simeq 150$, i.e., $L = 2.25$ cm.

This simplified analysis shows that laminar charge transport in capillaries occurs through a boundary layer type mechanism.

Conditions for Hazardous Electrostatic Environment

The conditions necessary for a hazardous electrostatic environment vary considerably, depending on whether the material under consideration is a gas, liquid, or solid. Although the hazard of greatest concern is production of an explosion, processes leading to spark ignition and subsequent flame propagation are also important. The latter is primarily of scientific or engineering importance, such as, for example, spark ignition of a fuel/air mixture in a flame tube for measurement of flame speed or inerting concentrations of various agents. Certainly various industrial fires can occur by spark ignition followed by flame propagation leading to fires; however, these are believed to be of lower priority than explosions.

At least the following conditions appear necessary for electrostatically induced discharges.

1. Generation and accumulation of electric charge—Many factors influence the former (see previous sections) whereas charge accumulation is the net difference between generation rate and dissipation to ground or another object (as, for example, in refueling operations where the other object could be a dip stick).
2. Accumulation of maximum charge an object can sustain in its environment, followed by self-excitation of the environment or induced breakdown—The discharge process is broadly classified into two categories of increasing intensity: corona or spark discharge types. Factors influencing the breakdown process are known to include: nature of charged surface, geometry (needle points vs hemispherically capped cylinders) and distance of external objects from charged surface, dry air environment [moist or high RH, or

inert gas (He or Ar inhibit breakdown)], and others. This is an area where it is rather difficult to make useful generalizations. Therefore, we will limit discussion to specific accepted approaches following a brief discussion on conditions necessary for an explosive environment.

Conditions necessary for explosions in gaseous fuels and liquids in air are:

1. Gases—Fuel concentrations must be within the upper and lower explosion limits and the electrostatic discharge must be sufficiently energetic to produce ignition.

2. Liquids—The conditions of (1) apply for liquids at temperatures corresponding to their flash pionts. For liquids present in aerosol form (i.e., mists) it is well-known that flammable mist-vapor oxidant mixtures can be formed at temperatures below the flash point.[31]

For suspended dusts the review by Hughes[32] shows an even more complex picture. Here the dust concentration must fall within certain limits and a portion of the cloud must be raised to its ignition temperature. The following factors influence ignition and subsequent combustion of the dust cloud: (1) physical characteristics of the particles, (2) temperature necessary for propagation, and (3) factors of flame propagation through the cloud (inert particles, moisture, and O_2 concentration). For electrostatic discharge to induce ignition of the dust cloud, the energy dissipated during discharge would have to heat a portion of the cloud to its ignition temperature.

Some electrostatic values useful in hazard assessment are given in Table 6. The minimum ignition energy in A is defined as the total energy transferred from a capacitor in a discharge[33] where C is capacitance in micromicrofarads, V is potential in volts, and Q is charge in coulombs. The appropriateness of applying this steady state equation to realistic discharges such as those occurring from a charged fuel surface has been questioned by Leonard and Carhart[34, 35] and others. Some parameters which may affect E include relative humidity, surface area, physical and chemical characteristics of materials, electrode geometry and dimensions, and fixed or moving objects. The usefulness of the minimum ignition energy concept follows from a simple example. Let us assume that a human is charged to 5,000 V by walking over a dry carpet and take his capacitance as 200 $\mu\mu$f; then we obtain $E = 2.5$ mj. This is of sufficient energy to ignite gaseous mixtures such as diethyl

TABLE 6
Some electrostatic values useful in hazard assessment

A) MINIMUM IGNITION ENERGY: 0.1 mj vapors in air
1 mj mists in air
10 mj dusts in air

$$E = CV^2/2 \times 10^{-9} = QV/2 \times 10^{-9} \text{ mj}$$

B) TYPICAL VALUES OF CAPACITANCE IN $\mu\mu$f, POTENTIAL IN VOLTS:
human being—$C = 100$-400; dry carpet or auto seat—5,000 V
automobile—$C = 500$; traveling over pavement—10,000 V
belts over pulleys—$C =$ variable; 20,000—25,000 V

C) PERCENTAGE OF THEORETICAL MAXIMUM CHARGE DENSITY
$\left(2.65 \times 10^{-9} \dfrac{\text{coul}}{\text{cm}^2}\right)$
sliding and rolling contact—up to 8%
dispersion of dusts—1 to 10%
pneumatic transport of solids and sheets pressing together—up to 60%
close machining—up to around 100%

ether/air over approximately 3 to 8%, and various mists in a more restricted concentration range.

The magnitude of static hazards may also be assessed in terms of charge per given area (coul/cm^2). The theoretical maximum charge density (area basis), i.e., the value that produces a field strength equal to the breakdown strength of air in a homogeneous field, is 2.65×10^{-9} coul/cm^2. Gibson and Lloyd[36] found that if polyethylene is charged to $1.1–2.2 \times 10^{-9}$ coul/cm^2 depending on relative humidity, surface area, and electrode characteristics, the discharge energy is sufficient to ignite a number of flammable vapor/air mixtures.

Accepted methods for control of static electricity[1,37] include:

1. Grounding—Grounding is useful for conductors and semiconductors; however, for very good insulators (i.e., materials of low conductivity and, thus, high relaxation time—see Table 3) grounding cannot be particularly effective. Use of one or a combination of the following methods is necessary for insulators.
2. Humidification—Increasing the relative humidity (RH) is particularly helpful for static suppression on various solids through increasing a) surface conductivity and b) volumetric conductivity if the material absorbs water (is hygroscopic). For gaseous fuel/air mixtures humidification is also helpful since the minimum ignition energy increases with %RH. However, for liquids, water leads to pronounced charging by settling mechanisms[38] and, consequently, humidification would not appear applicable to many processes involving liquids.
3. Increasing electrical conductivity—By adding antistatic additives, such as Shell A.S.A. Nos. 1 and 3, to hydrocarbon liquids or using aerosol sprays on solid surfaces.
4. Relaxation techniques—Mentioned previously.
5. Ionization—Use of radioactive materials, corona discharge, and inductive devices (such as grounded combs, bristles, and tinsel bars) is also helpful in providing a conductive path to ground.

Other techniques come to mind; however, they are usually very specific or often employ combinations of the above. Control of static at the manufacturing level is evidenced by the availability of various types of conducting plastics and carpeting (usually containing metallic fibers woven into the fabric). Recent development of so-called "epitropic" fibers seems to offer promise for eliminating static in fabrics.[39]

In the area of control, the introduction of new techniques is a very difficult task. One recent technique, applicable to refueling operations, is due to Leonard and Carhart (see page 209).

Practical Example

Application of the principles developed herein to problems involving routine charging in filters and turbulent and laminar flow in capillaries and tubes follows readily and, consequently, will not be considered in this section. Here we consider a problem of a somewhat different nature: the attempt, in general terms, to show the possibility of occurrence of electrostatically induced ignition in mist (liquid aerosol)/gaseous discharge of low dielectric constant fluids issuing from pressurized chemical reactors.

Let us consider a hypothetical chemical reactor as consisting of a cylindrical vessel containing some organic chemical (i.e., a typical low conductivity liquid—

see Table 3) in presence of a gaseous mixture (one component being oxygen) protected for rupture of the vessel by several standard 10 in. diameter carbon disks of mean rupture pressure 40 psig. Let us furthermore assume that the pressure in a given section of the reactor exceeds the disk rupture pressure and that the contents of the reactor pass through a 90° elbow (inclined vertically upward for protection of workers). Now a gaseous jet containing liquid aerosol particles formed by impaction of the fluid stream with the rupture disk and the 90° elbow will issue from the reactor. Since the pressure ratio on the reactor, P_o (psia) to ambient pressure P_a (14.7 psia) is $P_o/P_a > 2$, the overall flow will be sonic. Droplets of sufficiently small diameters and low density will be carried along by the jet at velocities equal to the stream velocity. Large drops will be unstable in this environment and will tend to form smaller droplets. Droplet flow velocities can be calculated as functions of particle radii, density, gas velocity, etc., for known drag coefficients using the equations for two-phase flow. However, this is clearly beyond the scope of this study.

Now, for a sonic jet and ideal gas assumption, flow velocity is given by

$$U_o = \sqrt{1.4\, R_{mix} T_o}, \tag{34}$$

where

$$R_{mix} = \sum_i X_i M_{wi},$$

and the specific heat ratio ($\gamma = c_p/c_v$) for an ideal gas is 1.4. A value of $U_o =$ 1000 ft./sec. from $R_{mix}T_o = 7.15 \times 10^5$ ft²/sec² is a fairly representative value of U_o to illustrate static hazard. If we assume the current for turbulent flow through pipes is roughly given by

$$I = \frac{\pi \epsilon \epsilon_o R T v}{2 n_+ F} \left(0.0223\, Re_{d_p}{}^{7/8}\, Sc^{1/4}\right), \tag{35}$$

where

$$Re_{d_p} = \rho v\, d_p/\mu,$$

with d_p the mean diameter of the liquid aerosol, and taking $Sc = 500$, $D = 10^{-5}$ cm²/sec, $\rho = 1$ gm/ml (therefore, $\mu = 5 \times 10^{-3}$ gm/cm sec), and $\epsilon = 2$, the above equation reduces to

$$I = 4.8 \times 10^{-11}\, Re_{d_p}{}^{7/8} \text{ amp.}$$

Now, the current may be related to the charge density Q_A (coul/cm²), the relaxation time and cross-sectional area, A, of the particle through

$$I = Q_A A/\tau, \tag{36}$$

where $A = 4\pi r^2$ for a spherical particle. The conductivity K contained in τ is another unknown; it is generally between $10^{-7}\Omega^{-1}\text{cm}^{-1}$ and $10^{-14}\Omega^{-1}\text{cm}^{-1}$ (Table 3). Taking $K = 10^{-7}\Omega^{-1}\text{cm}^{-1}$ and solving for Q_A we obtain

$$Q_A = 8.5 \times 10^{-17}\, Re_{d_p}{}^{7/8}/A. \tag{37}$$

The tabulated values for Q_A in Table 7 are quite interesting. This implies that discharges can occur for particles somewhat less than 10 microns since the charge density for corona discharge in air is only 2.6 x 10^{-9} coul/cm^2.

However, since $Q_A \propto 1/K$, much higher values of Q_A are possible for fluids of $K < 10^{-7}\Omega^{-1}\text{cm}^{-1}$. For example, for $K = 10^{-14}\Omega^{-1}\text{cm}^{-1}$ the Q_A values in Table 7 would all be multiplied by a factor of 10^7 giving values of Q_A that are believed more than necessary for spark-induced ignition (assuming, of course, that we are inside the flammability limits) even allowing for large errors inherent in this very approximate analysis.

TABLE 7
Calculated charge density dependence for spherical particles and sonic flow conditions ($v = 1000$ ft/sec); $\kappa = 10^{-7}\ \Omega^{-1}\ \text{cm}^{-1}$

dp (microns)	A (cm^2)	Q_A (coul/cm^2)
1000	$\pi \times 10^{-2}$	4.9×10^{-11}
100	$\pi \times 10^{-4}$	6.5×10^{-10}
10	$\pi \times 10^{-6}$	8.7×10^{-9}
1	$\pi \times 10^{-8}$	1.2×10^{-7}

Thus, we can see that electrostatically induced ignition is possible under certain conditions for various types of chemical reactors.

APPENDIX A

Tentative Theory of Charge Generation in Filters (Microporous Media)

The type of porous material considered here is a solid that contains a large number of interconnected holes (often referred to as pores) distributed throughout its volume. The Millipore filters, in particular, are porous media with pore diameters very small with respect to other characteristic lengths associated with the charge transport problem. Hence, they may be termed microporous media. Fluids in their motion through porous media may travel distances many times greater than the thicknesses of the media if the pore paths are extremely tortuous and/or interconnected. It is extremely difficult, if not impossible, to describe the fine features or microstructure of the flow field in terms of physically measurable parameters. For this study, an overall macroscopic approach, valid when one deals with regions in space containing a large number of pores, will be considered.

The equation of motion that describes flow in porous media and accounts for distortion of velocity profiles near containing walls[40] is

$$\nabla p = -\frac{\mu}{\kappa}\vec{v}_o + \mu\nabla^2\vec{v}_o + \rho\vec{g}. \qquad (1A)$$

Eq. 1A minus the viscous term, $\mu\nabla^2 v_o$, is the familiar Darcy law* for flow through

* Comprehensive discussions of Darcy's law, its applicability and limitations, are given in monographs by Scheidegger[41] and Collins.[42]

porous media. The velocity, v_o, is the superficial velocity which is related to the pore velocity, v_p, by

$$v_p = v_o/P = \frac{Q_m}{A_v},$$

where

$Q_m =$ measured volumetric flow rate, cm³/sec,
$A_v = PA_c =$ void area, cm²,
$A_c =$ cross-section area, cm²,

and P is the porosity given by

$$\%P = V_p/V_t \times 100\%,$$

where V_p is the pore volume and V_t is the total volume (solids plus voids). The permeability, κ, may be interpreted as a measure of the ease of flow through a porous medium (high values indicate ease of flow while low values indicate the contrary). By analogy with flow through single tubes, one may write the Reynolds number and friction factor (a measure of resistance to flow) as:

$$Re_{d_p} = \rho v_p d_p/\mu,$$

$$\text{and } f = \frac{d_p \Delta p}{\rho L_f} \left(\frac{A_v}{Q_m}\right)^2,$$

where

$\Delta p =$ pressure drop imposed over the filter thickness, L_f.

If we now apply Eq. 1A to the porous medium sketched in Fig. 1A and assume that the medium exhibits overall cylindrical geometry, then for constant κ and gravity free flow we obtain:

$$\frac{d^2 v_o}{dr^2} + \frac{1}{r}\frac{dv_o}{dr} - (1/\kappa)\, v_o = \frac{\Delta p}{\mu L}. \quad (2A)$$

Solution to Eq. 2A subject to no slip at $r = a$ and with v_o remaining finite for all values of r is:

$$v_o = \frac{\kappa \Delta p}{\mu} \left\{1 - \frac{I_o(r/\sqrt{\kappa})}{I_o(a/\sqrt{\kappa})}\right\}. \quad (3A)$$

Averaging v_o over the cross sectional area, we obtain:

$$\overline{v}_o = \frac{\int_o^a v_o r dr}{\int_o^a r dr} = \frac{\kappa \Delta p}{\mu L_f} \left\{1 - \frac{2\sqrt{\kappa}}{a} \frac{I_1(a/\sqrt{\kappa})}{I_o(a/\sqrt{\kappa})}\right\}. \quad (4A)$$

Eq. 4A minus the bracketed terms is Darcy's law. By plotting $1 - \dfrac{I_o(r/\sqrt{\kappa})}{I_o(a/\sqrt{\kappa})}$ vs r/a for a range of values $a/\sqrt{\kappa}$, we see that $I_o(r\sqrt{\kappa})/I_o(a\sqrt{\kappa})$ approaches zero. Thus, for $a/\sqrt{\kappa} > 10$, Darcy's law is applicable for flow through porous filters. The validity of $a/\sqrt{\kappa} > 10$ is readily confirmed by using Darcy's law to calculate the permeability:

$$\kappa = \frac{Q_m \mu}{A_v(\Delta p/L_f)}. \tag{5A}$$

Values of κ for the filters in Table 4 ranged from 1.1 x 10^{-12} cm^2 to 4.2 x 10^{-10} cm^2. Since a = 1.25 cm, $a/\sqrt{\kappa} \gg 10$ and, therefore, the above approach is valid. Strictly speaking, L_f in Eq. 5A should be L_{eff}, i.e., the effective filter thickness which accounts for the actual fluid flow path through the porous filter. This is usually accounted for in an empirical manner by the introduction of a correction factor called the tortuosity, t_o, into a geometrical model of the porous medium from which κ can be determined. For the simplified model of a bundle of straight, non-interconnecting, cylindrical tubes of uniform pore diameter the tortuosity is usually introduced as t_o^2 to give [41]

$$\kappa = \frac{P d_p^2}{32 t_o^2}. \tag{6A}$$

By comparison of values of κ from Eq. 6A with Eq. 5A, values of t_o were obtained ranging from $0.6 \leq t_o \leq 2.3$, with a few values ranging between 0.86 to 1.33. Thus, the Millipore filters under consideration here are rather representative of an ideal porous medium.

For the simplified model of the porous medium given above, it can be shown (for the assumption that the thickness of the charge transfer layer is small with respect to the pore diameter) that Eq. 5 may be written as

$$\frac{D\tau_o}{d_p^2}\left.\frac{dq_r}{dr_r}\right|_{c.t.l.} - (q_r^2+1)^{1/2} q_r - \left(\frac{v_p \tau_o}{d_p}\right)\frac{dq_r}{dx_r} = 0, \tag{7A}$$

where

$$q_r = q/Fc^\circ, \; r_r = r/d_p,$$

$x_r = x/d_p$, and *c.t.l.* = charge transfer layer.*

The boundary condition at *c.t.l.* can be shown to be

$$(D\tau_o/d_p^2)\frac{dq_r}{dr_r} = \frac{h\tau_o}{d_p}(q_r^2+1)^{1/2}. \tag{8A}$$

The usual entry condition for a fluid entering the filter uncharged is

$$q_r|_{x_r=o} = 0. \tag{9A}$$

Solution of Eq. 7A, subject to Eqs. 8A and 9A, gives

$$q_r = A - \frac{1+A^2}{\sinh\{(1+A^2)^{1/2}\dfrac{x}{v_p\tau_o} + B\} + A}, \tag{10A}$$

* The boundary condition is written in terms of a charge transfer coefficient, h. We, therefore, assume there is a region very close to the surface where q is a function of r, i.e., the charge transfer layer. Its extent of penetration into the liquid is the charge transfer layer thickness.

where $A = h\tau_o/d_p$ and $B = sinh^{-1}\ (1/A)$. In order to apply Eq. 10A, the functional form of the charge transfer coefficient must be determined. This will be accomplished by dimensional analysis.

The dimensional analysis approach given on page 208 is applicable here; however, we wish to show that similar results can be obtained using a slightly different approach. In the general case one expects the charge transfer coefficient to be a function of the same independent parameters as the measured current. However, by analogy with mass transfer coefficients which are assumed independent of concentration differences, h may be taken independent of $Fc°$ (coul/cm^3). In addition, since h should depend on interfacial parameters, not bulk parameters, it must also be independent of A_v. Thus, h may be written as a function of v_p, L_p, ν, τ_o, and d_p. Carrying out the analysis similar to that on page 208, we obtain the following dimensionless groups:

$$\pi_{1h} = h\tau_o/d_p, \tag{11A}$$

$$\pi_{2h} = v_p\tau_o/d_p = Re_{d_p}Sc\ (\delta/d_p)^2, \tag{12A}$$

$$\pi_{3h} = L_p/d_p, \tag{13A}$$

$$\pi_{4h} = \nu\tau_o/d_p{}^2 = Sc(\delta/d_p)^2. \tag{14A}$$

According to the π theorem,

$$h\tau_o/d_p = \Phi\ (v_p\tau_o/d_p)^\alpha\ (L_p/d_p)^\beta\ (\nu\tau_o/d_p{}^2)^\sigma, \tag{15A}$$

where Φ is a constant of proportionality and α, β, σ are constants. If we write the left hand side of Eq. 15A as $(hd_p/D)\ (D\tau_o/d_p{}^2)$ and use the right hand side of Eqs. 12A and 14A, then hd_p/D, which is a Nusselt number, may be written as

$$Nu = hd_p/D = \Phi' Re_{d_p}{}^{\alpha'} Sc^{\beta'}\ (\delta/d_p)^{\sigma'}\ (L_p/d_p)^{\omega'}. \tag{16A}$$

Note the similarity of Eq. 16A and Eq. 10. Since Eq. 10A contains $h\tau_o/d_p$ terms, Eq. 15A is preferred to Eq. 16A for this work.

In order to compare Eq. 10A with Eq. 27, we substitute

$$v_p = Q_m/A_v \text{ and } q_m = I_m/Q_m \tag{17A}$$

(q_m is the mean charge density obtained from the measured current for a given volumetric flow rate) into Eq. 27 and obtain:

$$q_m/Fc° = 2 \times 10^{-4}\ (v_p\tau_o/d_p)^{0.75}. \tag{18A}$$

Now the only way Eq. 10A can equal Eq. 18A is for $\{1 + (h\tau_o/d_p)^2\}^{1/2}\ L_p/v_p\tau_o \gg 1$. For this case Eq. 10A reduces to

$$q/Fc_o = \Phi\ (v_p\tau_o/d_p)^\alpha (L_p/d_p)^\beta (\nu\tau_o/d_p{}^2)^\sigma,$$

which is identical to Eq. 18A for $\Phi = 2 \times 10^{-4}$, $\alpha = 0.75$, $\beta = \sigma = 0$. However, it is not possible to show that $\{1 + (h\tau_o/d_p)^2\}^{1/2} \times L_p/v_p\tau_o \gg 1$ by direct substitution, since L_p, the pore length, is indeterminate and since h was determined by means of this approximation.

Since the analysis was based on the assumption that the thickness of the charge transfer layer is small with respect to the pore diameter, this condition should be verified from the data. By analogy with ordinary mass transfer

$$d_{c.t.l.} = d_p/Nu. \tag{19A}$$

A suitable Nusselt number is available in $h\tau_o/d_p$ (compare Eq. 15A with Eq. 18A)

$$Nu = h\tau_o/d_p = 2 \times 10^{-4} \left(\frac{v_p\tau_o}{d_p}\right)^{0.75} = 2 \times 10^{-4}\, Re_{d_p}{}^{0.75}\, Sc^{0.75}, \qquad (20A)$$

where Sc was used to replace $\nu\tau_o/d_p{}^2$.

Values of Nu from Eq. 20A and $d_{c.t.l.}$ from Eq. 19A are listed as functions of $v_p\tau_o/d_p$ in Table 1A.

TABLE 1A
Nusselt number and charge transfer layer thickness for typical values of $Re_{d_p}Sc(\delta/d_p)^2$

$Re_{d_p}Sc(\delta/d_p)^2$	Nu	$d_{c.t.l.}/d_p$
10^7	36.5	0.03
10^6	6.34	0.16
10^5	1.13	0.89
10^4	0.50	2.00
5×10^3	0.12	8.35

Although $d_{c.t.l.}/d_p$ is properly small when $v_p\tau_o/d_p$* $\gtrsim 10^6$, it is apparently too large for smaller values $v_p\tau_o/d_p$. From Fig. 5 the actual limit of applicability of the development is $v_p\tau_o/d_p = 5 \times 10^3$. Although one can offer many reasons for roughly a 30-fold reduction of $d_{c.t.l.}/d_p$ at $v_p\tau_o/d_p = 5 \times 10^3$, it is difficult to provide firm support for these assertions. Certainly $d_{c.t.l.}$ as calculated here really represents an average over the cross-sectional area of the filter and the actual pore length and, consequently, should not be compared with d_p.

Besides the drawbacks noted above, there is one additional factor not immediately obvious from this development for conductivities around $10^{-13}\Omega^{-1}cm^{-1}$ to $10^{-14}\Omega^{-1}cm^{-1}$ corresponding to the data in Fig. 5, for $v_p\tau_o/d_p \gtrsim 10^5$. Here, the total number of ions contained in a given pore is so low that continuum theory would not be expected to be valid. This does not appear to be a serious drawback, since one can examine regions in space that contain a large number of ions, similar to the restriction of the fluid flow equations to regions in space that are large with respect to a characteristic dimension.

In summary, recognizing many unsatisfactory points in the development, it is hoped that future studies may resolve these points or that one's interest may be stimulated to pursue different approaches to handle this complex problem.

* Recall that $v_p\tau_o/d_p = Re_{d_p}Sc(\delta/d_p)^2$.

Nomenclature

a tube radius, cm
A area, cm^2
A_c cross-sectional area, cm^2
A_v void area, cm^2
$c_{\pm}$ concentration of positive or negative ions, mol/cm^3
c_o concentration of ions in bulk liquid, mol/cm^3
c_s concentration of ions at surface, mol/cm^3
c^o total ionic concentration, mol/cm^3
c_p specific heat at constant pressure
c_v specific heat at constant volume
C capacitance, micromicrofarads ($\mu\mu$f)
d diameter, cm
$d_{c.t.l.}$ charge transfer layer thickness, cm
d_p pore diameter, cm
$D_{\pm}$ diffusivity of positive or negative ion, cm^2/sec
D' imbalance of diffusivities, $\frac{D_+ - D_-}{2}$. cm^2/sec
D mean diffusivity of positive and negative ions, $\frac{D_+ + D_-}{2}$, cm^2/sec
E minimum ignition energy, millijoules
f friction factor, dimensionless
F Faraday number, 96, 500 coul/mol
g acceleration of gravity, 980 cm/sec^2
G $d^2/Re^{7/4}\tau\nu = 1/Re^{7/4}\,Sc\,(\delta/d_p)^2$, dimensionless number
h charge transfer coefficient, cm/sec
I current, amps
I_d current density, $amps/cm^2$
I_m measured current, amps
I_∞ current for infinitely long tubes, amps
I_0 modified Bessel function of first kind, Zero order
I_1 modified Bessel function of first kind, First order
$j_{\pm}$ flux of charge of positive or negative ions, $coul/cm^2$ sec
j total charge flux, $coul/cm^2$ sec
J_0 Bessel function of Zero order
K electrical conductivity, $\Omega^{-1}\ cm^{-1}$
L characteristic length, cm
L_p pore length, cm
L_f filter thickness, cm
M_{wi} molecular weight of i-th component, gm/mol
n_+ transference number of positive ion, dimensionless
Nu Nusselt number, dimensionless
p pressure, $dynes/cm^2$
p_a ambient pressure, $dynes/cm^2$
p_o pressure inside reactor, $dynes/cm^2$
P porosity, dimensionless
Pe Peclet number, dimensionless
q volumetric charge density, $coul/cm^3$
q_m measured charge density, $coul/cm^3$
q_w charge density at wall, $coul/cm^3$
q_∞ free stream charge density, $coul/cm^3$
Q total charge, coulomb
Q' rate of charge transfer, coul/sec
Q_A charge per area, $coul/cm^2$
Q_m measured volumetric flow rate, cm^3/sec
r radial co-ordinate, cm
R gas constant, $8.32\frac{v - \text{coul}}{°K - \text{mol}}$
R_{mix} gas constant for mixture
Re Reynolds number, dimensionless
Sc Schmidt number, dimensionless
t time, sec
t_o tortuosity, dimensionless
T temperature, °K or °R
T_o reference temperature, °K or °R
u flow velocity, cm/sec
U characteristic flow velocity, cm/sec
U_o flow velocity for sonic conditions, cm/sec or ft/sec
v flow velocity, cm/sec
v_o superficial velocity, cm/sec
v_p pore velocity, cm/sec
V potential, volts
V_p pore or void volume, cm^3
V_t total volume (solids plus voids), cm^3
x axial distance, cm
x_o starting length, cm
X_i mole fraction i-th component, dimensionless
y distance off plate, cm
z distance in z direction
$Z_{\pm}$ charge on a univalent ion

Superscripts
$\bar{}$ averaged quantity
$'$ refers to model condition

Subscripts
r reduced or dimensionless variable

GREEK
γ specific heat ratio, c_p/c_v
δ Debye double layer thickness, cm
Δ thickness of charge boundary layer, cm
δ_v velocity boundary layer thickness, cm
θ angular co-ordinate
ϵ dielectric constant, dimensionless
ϵ_o permittivity of free space 8.85 x 10^{-14} sec/Ω-cm
η modified recombination coefficient
λ diffusion layer thickness, cm
κ permeability, cm^2
μ viscosity, gm/cm sec
μ_I ionic mobility, cm^2/v-sec
ρ density, gm/cm^3
ν kinematic viscosity, cm^2/sec
τ relaxation time, sec
τ_o initial or equilibrium relaxation time, sec
ψ potential, volts

References

1. Eichel, F. G. "Electrostatics," *Chem. Eng.*, pp. 153-167 (March 13, 1967).
2. Gavis, J. "The Origin of Electric Charge in Flowing Hydrocarbons," AIChE—6th Loss Prevention Symposium, San Francisco, California, November 1971.
3. Felici, N. J. "Electrostatics and Electrostatic Engineering," *Static Electrification*, Institute of Physics and Physical Society, Conference Series No. 4, London, May 1967.
4. Gavis, J. and Koszman, I. *J. Colloid Sci.* **16**, 375 (1961).
5. Koszman, I. and Gavis, J. *Chem. Eng. Sci.* **17**, 1013 (1962).
6. Koszman, I. and Gavis, J. *Chem. Eng. Sci.* **17**, 1023 (1962).
7. Gavis, J. *Chem. Eng. Sci.* **22**, 359 (1967).
8. Gavis, J. *Chem. Eng. Sci.* **22**, 365 (1967).
9. Gavis, J. and Wagner, J. P. "Charge Transport in Flow of Low Dielectric Constant Fluids Through Micro-Porous Media," *Chem. Eng. Sci.* **23**, 381 (1968).
10. Moore, A. D. "Electrostatics," *Scientific American* **226**(3), 46-58 (1972).
11. Harper, R. W. "How Do Solid Surfaces Become Charged," *Proceedings of Conference on Static Electrification*, pp. 3-10, London, May 1967.
12. Robinson, R. A. and Stokes, R. H. "Electrolytic Solutions," *Butterworths Sci. Pub.*, 2nd Edition, London, 1959.
13. Fuoss, R. M. and Kraus, C. A. *J. Am. Chem. Soc.* **55**, 2387 (1933).
14. Gavis, J. "Electrical Conductivity of Low Dielectric Constant Liquids by DC Measurement," *J. Chem. Phys.* **41**(12), 3787 (1964).
15. Gavis, J. "Transport of Electric Charge in Low Dielectric Constant Fluids," *Chem. Eng. Sci.* **19**, 237 (1964). (See also Ref. 7)
16. Wagner, J. P. "Charge Generation During Flow of a Hydrocarbon Liquid Through Micro-Porous Media," Ph.D. Thesis, Johns Hopkins University, Department of Chemical Engineering, September 1966.
17. Heidelberg, E. "Generation of Igniting Brush Discharges by Charged Layers on Earthed Conductors," 1967 *Static Electrification Conference Series* p. 154, The Institute of Physics and Physical Society, London, May 1967.
18. Luikov, A. V., Perelman, T. L. and Anisimov, S. I. "On Diffusion in Plasma with Recombination," *Int. J. Heat and Mass Transfer* **11**, 141-144, Pergamon Press, 1968.
19. *American Institute of Physics Handbook*, Section 5, p. 178, McGraw Hill, 1957.
20. *Handbook of Physics*, pp. 4-176, Second Edition, McGraw Hill, 1967.
21. Gibson, N. and Lloyd, F. C. "Electrification of Toluene in Pipeline Flow," *Proceedings of Conference on Static Electrification*, pp. 89-97, London, May 1967.
22. Gibbings, J. C. and Hignett, E. T. *Electrochem. Acta* **11**, 815 (1966).
23. Hignett, E. T. Ph.D. Thesis, University of Liverpool, 1963.
24. Deissler, R. G. *NACA Report 1210*, 1966.
25. Liebhafsky, H. A. and Cairns, E. J. *Fuel Cells and Fuel Batteries*, John Wiley & Sons, Inc., 1968.
26. Bruinzeel, C., Luttik, C., Vellenga, S. J. and Gardner, L. "A Study of Electrostatic Charge Generation During Low Temperature Refueling of Aircraft," *Aeronautical Report LR-387, NTC No. 7794*, National Research Council of Canada, Ottawa, 1963.
27. "Electrostatic Charging Characteristics of Jet Fuel Filtration Equipment," *CRC Report No. 458*, Coordinating Research Council, Inc., 30 Rockefeller Plaza, New York, N.Y.
28. Leonard, J. T. and Carhart H. W. "Effect of Conductivity on Charge Generation in Hydrocarbon Fuels Flowing through Fiber Glass Filters," *Journal of Colloid and Interface Science* **32**(3), March 1970.
29. Langhaar, H. L. *Dimensional Analysis and Theory of Models*, John Wiley and Sons, New York, 1951.
30. Levich, V. G. *Physiochemical Hydrodynamics*, Prentice Hall, 1962.
31. "Fire Hazards in Oxygen Enriched Atmospheres," *NFPA No. 53M*, pp. 36-38, National Fire Protection Association, Boston, Mass., 1969.
32. Hughes, J. W. "Dust Explosion," *Fire Research Abstracts and Reviews* **12**(1), 20, 1970.
33. Lewis, B. and Von Elbe, G. *Combustion, Flames and Explosion of Gases*, Academic Press, Inc., New York, 1961.
34. Leonard, J. T. and Carhart, H. W. "Electrical Discharges From a Fuel Surface," *Proceedings of Conference on Static Electrification*, pp. 100-11, London, May 1967.
35. Leonard, J. T. and Carhart, H. W. "Static Electricity Measurements during Refueler Loading," *NRL Report No. 7203*, Naval Research Laboratory, Washington, DC (January 5, 1971).
36. Gibson, N. and Lloyd, F. C. *Brit. J. Appl. Phys.* **16**, 1619, 1965.
37. Factory Mutual Engineering Corporation. *Handbook of Industrial Loss Prevention*, Chapter 30, McGraw Hill, 1967.

38. Klinkenberg, A. "Static Electricity in Liquids," *Proceedings of Conference on Static Electrification,* pp. 63-68, May 1967.
39. *Chemical and Engineering News,* p. 22 (December 3, 1973).
40. Brinkman, H. C. "On the Permeability of Media Consisting of Closely Packed Particles," *Appl. Science Research, A1,* pp. 27-34, 81-86 (1947).
41. Scheidegger, A. E. *The Physics of Flow Through Porous Media,* pp. 114-117, The Macmillan Company, New York, 1960.
42. Collins, R. E. *Flow of Fluids Through Porous Materials,* pp. 51, 77, Rheinhold Co., New York, 1961.

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Combustion Laboratory at the Warsaw Polytechnic University*

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Editor, Archiwum Procesow Spalania

Abstract

This article outlines an educational laboratory design for experimental studies in the field of combustion adapted, on the one hand, for the education of students and development of personnel for teaching institutes and, on the other, for collaboration with industry. Technical and organizational problems that must be solved during the establishment and operation of such a laboratory are discussed. Its funding and trends of research being conducted in it are described.

Introduction

The Combustion Laboratory of the Warsaw Polytechnic University was established from the facilities and personnel of the former Industrial and Aircraft Combustion Engine Department. That Department was organized in 1961 by combining the Combustion Engine Department, which specialized in piston engines, and the Aircraft Engine Department.

Combustion was chosen as the research field which would concentrate all the scientific work of the Department. This provided a common ground for creative scientific activity for the design staff, which is engaged in teaching a broad range of subjects of a theoretical and design nature (from piston compressors and rotary machines, high-pressure motors, to rocket engines).

The Laboratory was conceived in such a way that, on the one hand, students could be educated (mainly by performing their obligatory and degree work) and scientific personnel could be advanced (by carrying out their doctoral work and work qualifying them for assistant-professorships) and, on the other hand, so that it would be an attractive partner in the realization of research projects for industrial laboratories.

1. General Concept of the Laboratory: Technical and Organizational Aspects

The idea of building a combustion laboratory arose at the end of 1966 and work was started in the next year. At that time the Department, together with the auxiliary staff, numbered 45 people, including more than 20 design personnel, consisting of instructors, doctors, and scientific and technical assistants with ad-

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vanced education. The auxiliary staff had well-equipped mechanical workshops which carried out work for other state institutes.

The teaching staff of the Department, on the other hand, was organized on the traditional model, at least at the Warsaw Polytechnic. The Department was housed as follows: the professor's office, rooms for the assistants, and drafting rooms for the students (usually not for all those needing them).

In such a situation, the proposal to build a laboratory and to determine both the nature and the intended topical scope of the scientific activity of the collaborators met with their support, despite certain difficulties, among them the requirement of requalification of the "designers" as "scientists."

To solve the marginal problems and to give scientific production the proper standard, it was necessary to find substantial investment funds for the construction of test stands and measuring instruments.

Such funds could only be obtained in part from the educational institution. The rest had to be found in collaboration with industry. The need to conduct research and the necessity of cooperation of industrial institutes and institutions of advanced education in realizing this research is well recognized. The problems lie in the evaluation of mutual possibilities and optimizing the assignment of tasks. Our colleagues in advanced education generally enjoy the sympathy of industry, where they cooperate in solving technical problems. This attribute of the teaching staff and their chief duty of handling students, influenced the choice of scientific subjects undertaken at the advanced institutes.

In view of the urgent requirements of the national economy, the laboratory was obliged to engage in a study of the combustion of natural gas containing nitrogen and of coal as well as the study of combustion processes in high-pressure internal-combustion engines. This criterion for optional division of tasks between the industrial and educational studies had the nature primarily of basic research.

Within a short period of time the Department had signed a series of long-term contracts for the conduct of scientific investigations with several institutes including the Aeronautics Institute, the Central Internal-Combustion-Engine Design Bureau, the State Inspectorate of the Fuel and Energy Administration as well as the Power Engineering Institute. Contracts were also signed with the Instruments Division of the Warsaw Polytechnic for the development of certain devices and some parts of the Laboratory equipment.

The assistance of the Department in the collaboration of the designers with the affiliated institutes consists in the planning of test stands, while the workshop engaged in service activities builds them.

Rational research work in such a laboratory requires an appropriate technical backup; the following laboratories have been set up: electronic (Fig. 1), optical (Fig. 2), chemical (Fig. 3), photographic and a supplementary, auxiliary mechanical workshop (Fig. 4).

2. Combustion of Gas Fuels

The field of gas-fuel combustion is the best developed theoretically and the greatest number of experiments have been carried out in it, even though the practical value of such fuels is much lower than that of liquid and solid fuels. They are easy to handle, the processes can be readily interpreted, and it is easy to make measurements and visualize the phenomena. For these reasons gas fuels are always used when secondary effects of combustion processes are being studied (e.g., pressure fluctuations), while the chemical reactions act exclusively as heat sources.

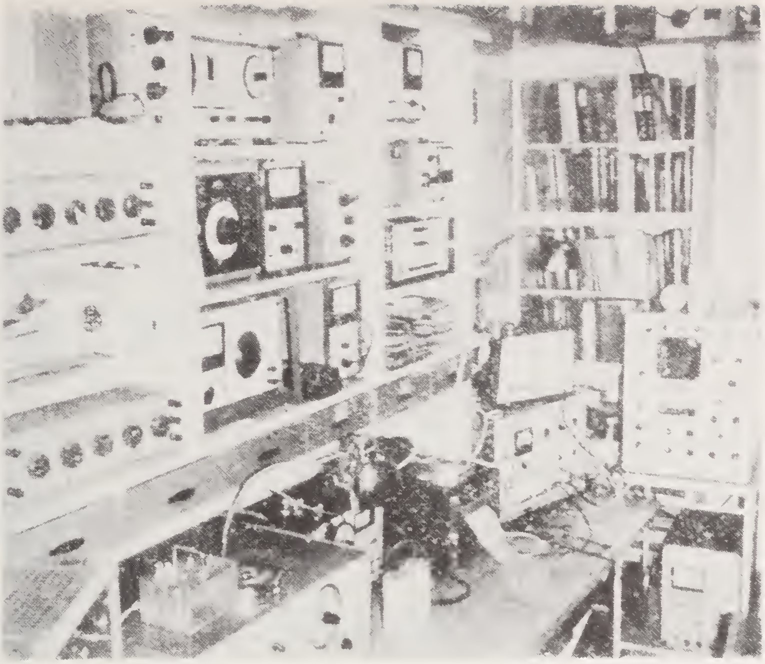

Fig. 1. Electronics laboratory

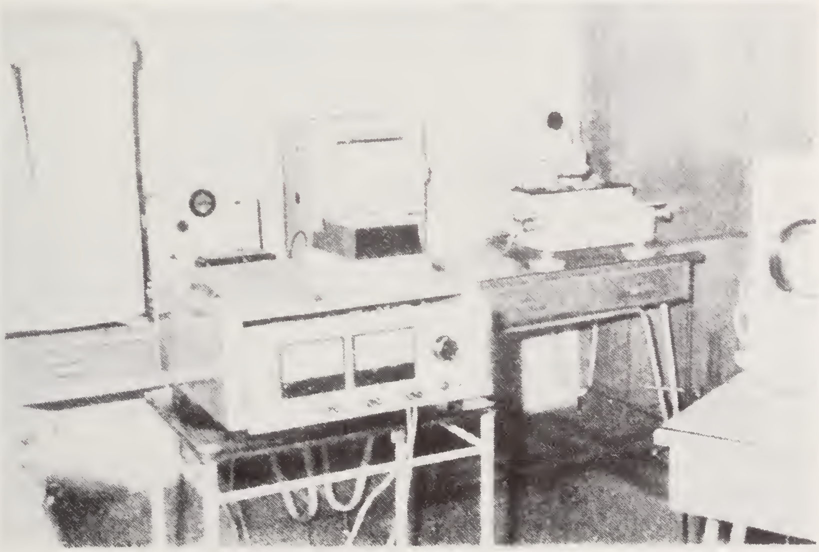

Fig. 2. Optical laboratory

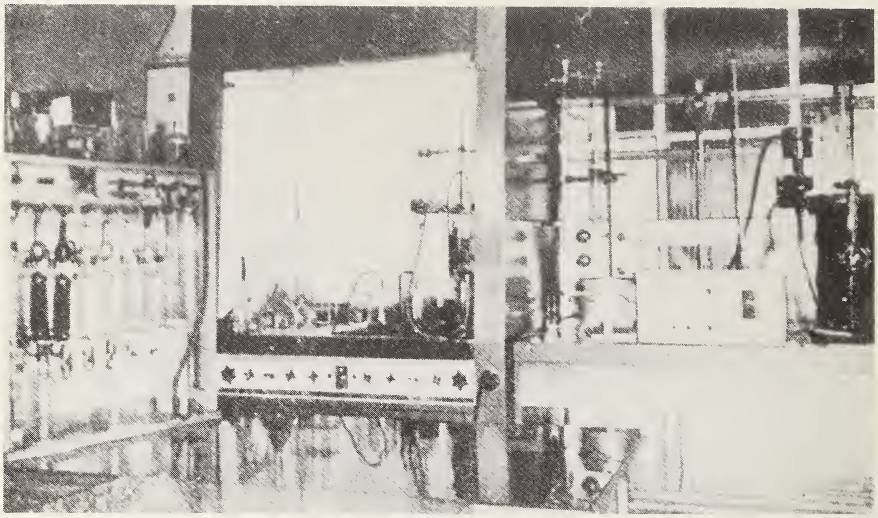

FIG. 3. Chemical laboratory

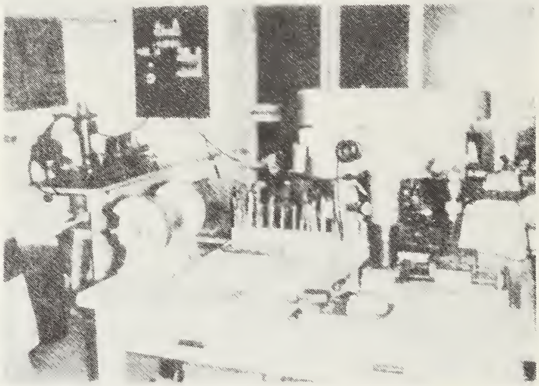

FIG. 4. Auxiliary mechanical workshop

The part of the Laboratory devoted to the investigation of gas-fuel combustion contains three test stands: to study laminar flames (Fig. 5), burner models (Fig. 6), and the partial methane burning process (Fig. 7).

The first stand permits study of the structure of laminar flames, both premixed and diffusional, over a broad range of pressures and temperatures, as well as determination of their speed of propagation, which is an important quantity characterizing the physico-chemical properties of fuel mixtures.

A laminar flame can be considered as a continuous reactor, in which the individual processes are stabilized, permitting us to monitor their course and to detect the successive mechanisms and relationships which are important for knowledge of the kinetics of a chemical reaction occurring during combustion.

The test stand for burner models facilitates the development of industrial-

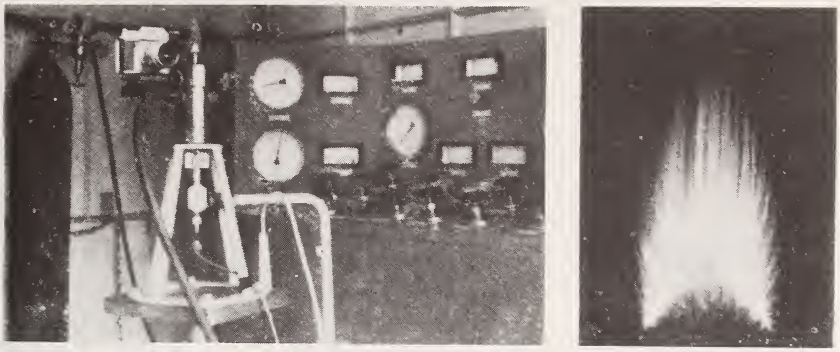

FIG. 5. Stand for the study of laminar flames: a) view of the test stand; b) kinetic laminar flame.

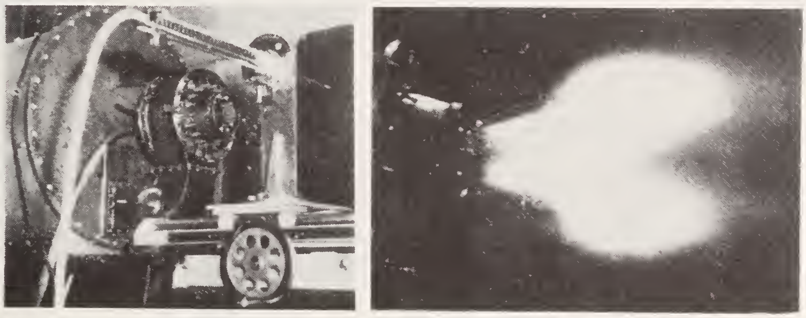

FIG. 6. Stand for the study of burner models intended for gas-fuel combustion: a) view of stand; b) view of the flame.

burner designs. It is equipped with instruments which permit measurement of the distribution of the thermodynamic parameters of a flame and the gas dynamic characteristics of combustion.

Partial methane combustion with incomplete oxidation produces acetylene. The process takes place in a continuous-action chamber which is fed with oxygen and methane, initially heated to a temperature of the order of 600°C. The products are cooled by a stream of water in order to contain the chemical reactions.

The stand shown in Fig. 7 serves to simulate these phenomena. Problems which still await solution are, above all, the finding of the optimal parameters of processes, or those which ensure the obtaining of maximum acetylene participation in engines and protection against pulsating combustion, which has the possible danger of explosion.

3. Combustion of Coal

The overall study of coal combustion is tied to the solution of a number of troublesome technical and organizational problems, connected with the preparation, storage, and transportation of coal dust. These problems substantially exceed

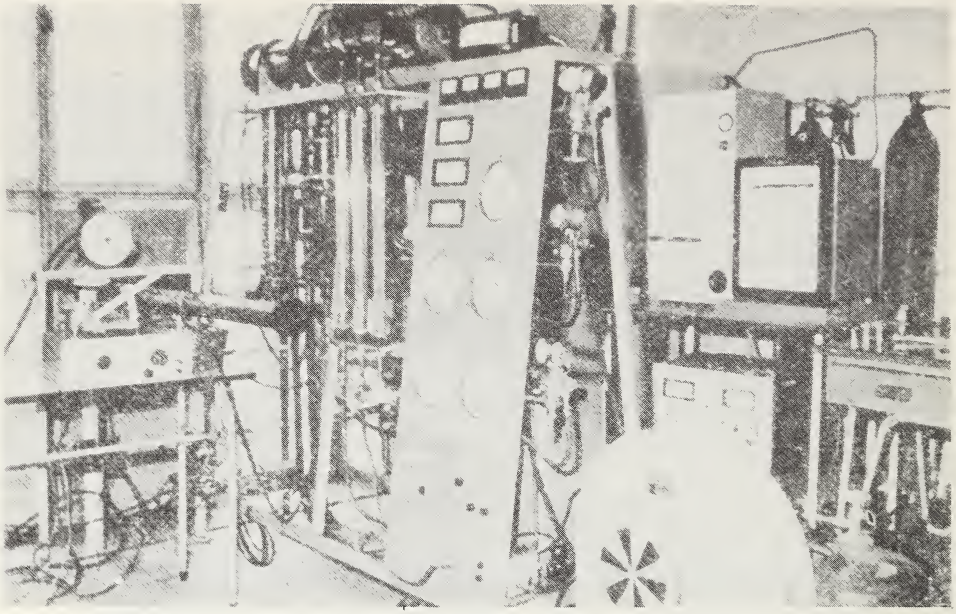

FIG. 7. Test stand for the investigation of partial methane combustion.

the capabilities of a small research organization. The most reasonable method of solving this problem, even for well-financed institutes, is to draw on representatives from electric power plants, thus making it possible to reduce the difficulties involved in organizing the work.

In this area the Laboratory has performed work on measuring the laminar combustion rate and flame stabilization in mixtures of coal dust and air. Two test stands shown in Figs. 8 and 9 were used.

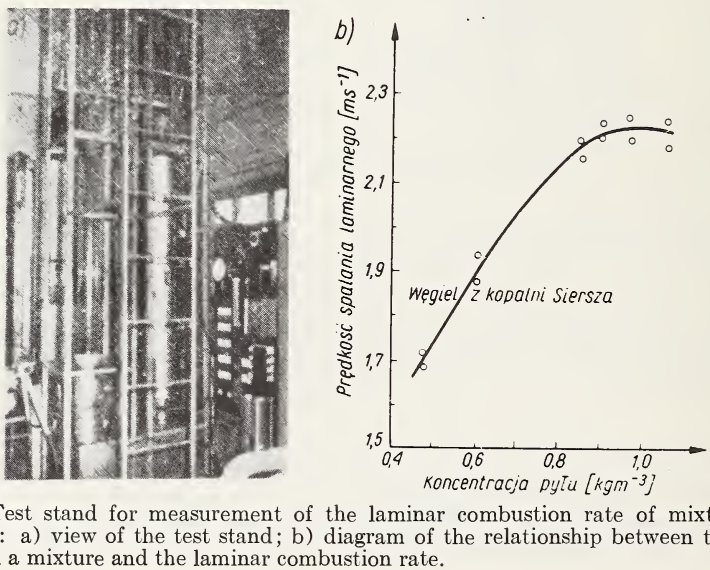

FIG. 8. Test stand for measurement of the laminar combustion rate of mixtures of coal dust and air: a) view of the test stand; b) diagram of the relationship between the dust concentration in a mixture and the laminar combustion rate.

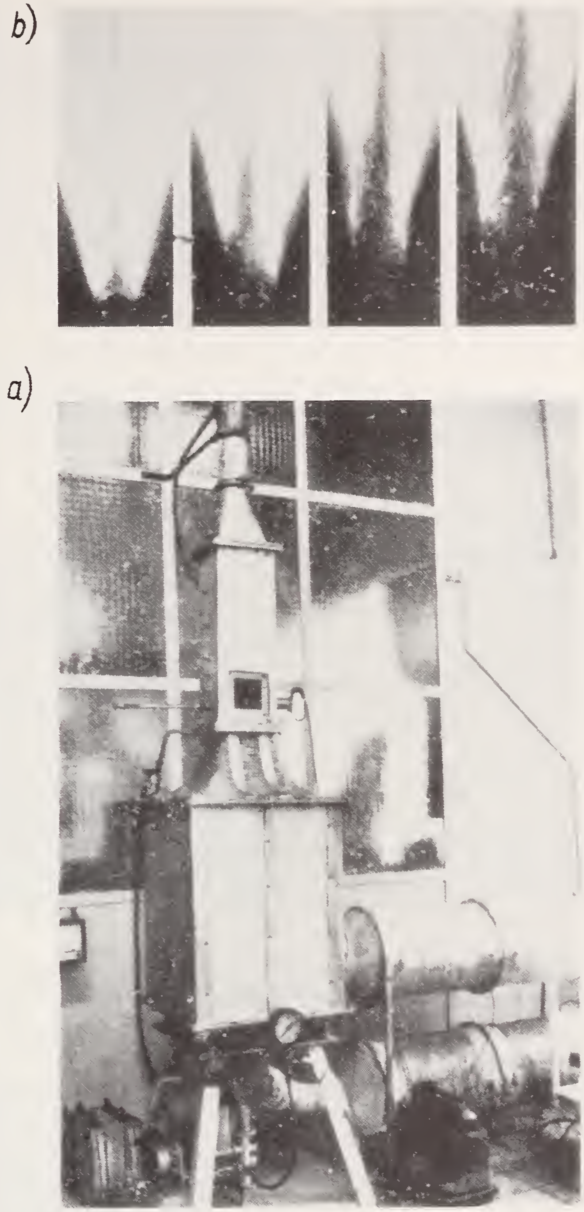

FIG. 9. Test stand for the study of flame stabilization in mixtures of coal dust and air: a) view of the test stand; b) flame jet downstream of a stabilizing rod.

The test stand for measuring the laminar combustion rate is made up of vertical conduits supplied from the top with a mixture of freely falling dust (a fluidized feeder is used for this purpose) and air. The mixture is ignited in the lower part of the conduit, and the speed of the flame moving upward is recorded.

The speed is determined by recording the signals transmitted by built-in photodiodes and by measuring the tangent of the angle of the flame front recorded photographically (Fig. 6b). The results of a series of measurements is shown in Fig. 8b.

The aim of such investigations is to determine the laminar combustion rate of Polish coal under selected conditions. It is assumed that this quantity sufficiently characterizes the physico-chemical properties of the dust-air mixtures and that it is directly related to the combustion rate that occurs in furnaces. Such determinations would have great practical value and are projected.

The principal component of the test stand for flame stabilization in depleted dust-air mixtures is the combustion chamber with controlled wall temperature. The chamber is supplied with a mixture having a regulated rate and thermodynamic parameters. A quartz window built into the chamber makes it possible to photograph and film the investigated processes (Fig. 9b).

This test stand is being used for studies of flame stabilization behind an unstreamlined body. This is the simplest case of stabilization used in furnaces by circulating the combustion gases. The results are of general value and are widely used.

4. *Combustion in High-Pressure Engines*

Ten years ago many specialists held the opinion that the development of piston combustion engines had reached a plateau. This opinion stemmed from the conviction that classical propulsion systems would be shortly displaced by new equipment, and that they would be used only for marginal tasks. In view of this, the allocation of funds to advance the design of such engines would be purposeless at this time. We now know, however, that we will have to wait longer than we expected for more modern systems to replace the classical engines. Now more general and deeper research into engine processes in high-compression engines has been encouraged.

The problem of studying engine combustion is connected with limiting their specific power. These limiting factors are: the prevalence of knock (the external sign of excessively strong combustion, causing, in turn, excessively long self-ignition lag of the fuel) and atmospheric pollution (soot and toxic combustion-gas components).

Investigation of internal-combustion is difficult because the process is not steady in time and requires complex and skillful experimental methods.

The Laboratory is investigating the phenomena affecting burning a single shot of fuel (Fig. 10) as well as the influence of physico-chemical properties of fuel and conditions of combustion (thermodynamic parameters, the conditions of fuel mixing, etc.) on the magnitude of the self-ignition lag (Figs. 11 and 12).

5. *Gas Dynamics of Combustion*

The influence of reaction product motion on combustion occurred in jet engines. It cannot be regarded as a static phenomenon.

Problems of the gas dynamics of combustion are flame stabilization, pulsating combustion, detonation, and nonstationary phenomena, such as ignition and the transition of combustion into detonation.

Shown in Fig. 13 are two test stands for the investigation of pulsating combustion. The basic unit of the first (Fig. 13a) is the acoustic generator, which affects the diffusion burner. The effect of this type of action is shown in three

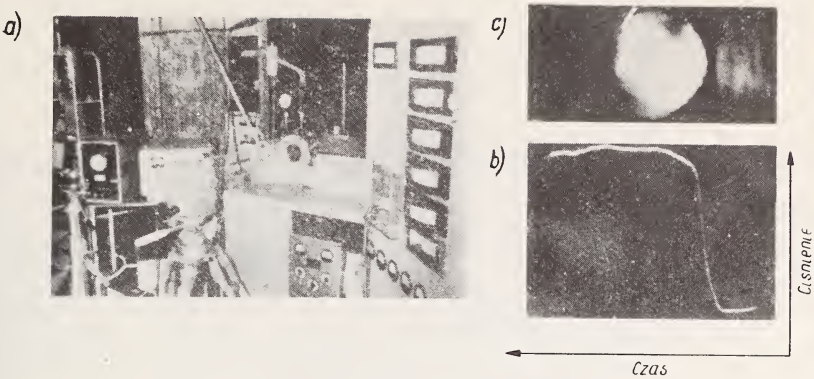

FIG. 10. Test stand for the study of combustion of single shots of liquid fuel in a constant-capacity chamber: a) view of the stand; b) pressure distribution in the chamber during combustion; c) frame of film recording the course of combustion.

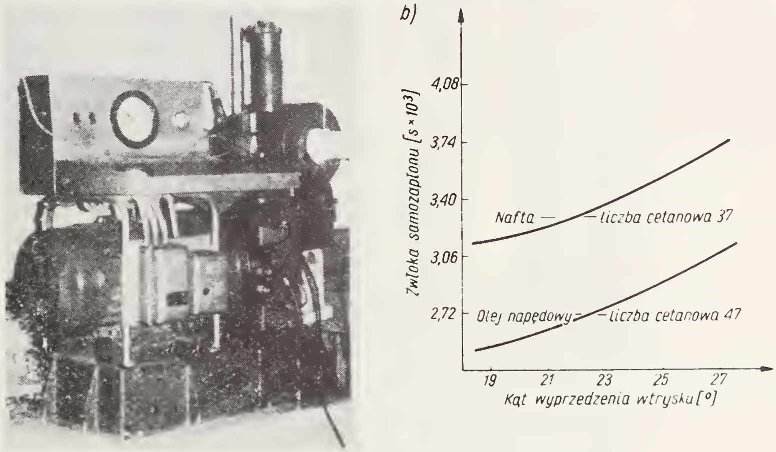

FIG. 11. Stand with an experimental BASF-MWM internal combustion engine: a) view of the stand; b) dependence of the liquid-fuel self-ignition lag on the injection angle.

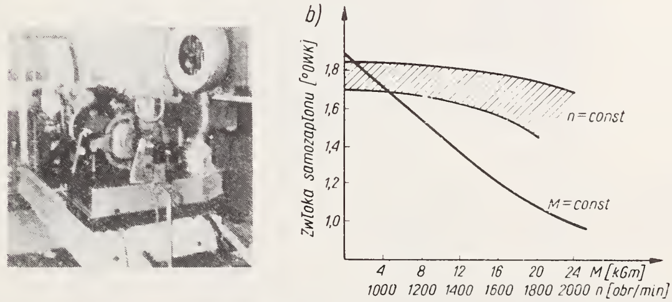

FIG. 12. Stand for the study of combustion processes in high-compression engines: a) view of a stand with an engine of the Commer type; b) dependence of the self-ignition lag (measured in degrees of crankshaft rotation) on the speed of revolution n at constant rotational moment M and on the rotational moment at constant velocity n.

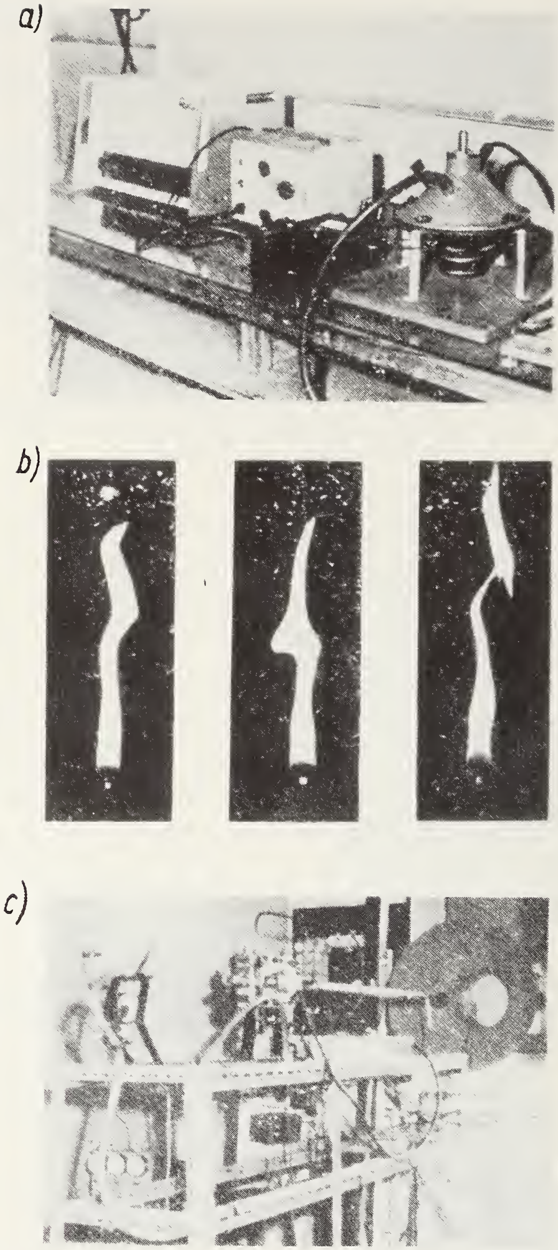

FIG. 13. Stands for the study of pulsating combustion: a) stand for the study of the influence of acoustic vibration on diffusion combustion; b) influence of acoustic vibration on diffusion combustion; c) stand for the study of combustion in pulsating engines.

flame photographs (Fig. 13b) illustrating three successive stages. The other stand is used to study combustion in a pulsating engine. Quartz windows are built into the chamber, making it possible to view the phenomena.

A characteristic feature is the fact that with the stands it is possible to study pulsating combustion generally. The aim of the investigations is to understand the feedback mechanisms and facilitate their control.

Shown in Figs. 14 and 15 are two shock tubes, one of which (Fig. 15) is used

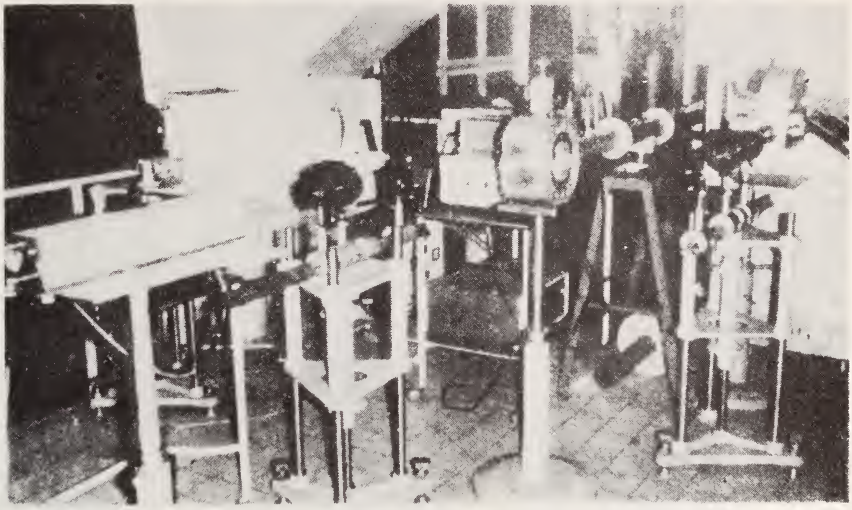

Fig. 14. Shock tube with equipment for schlieren photography.

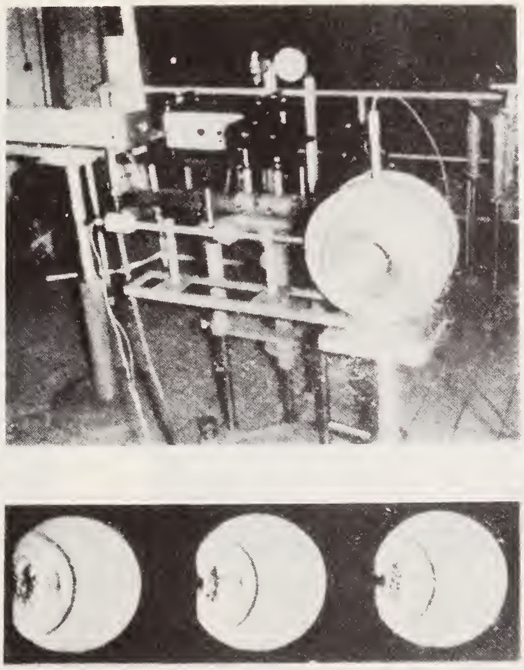

Fig. 15. Stand for the study of spatial detonation: a) view of the stand; b) film frames of the ignition of a gaseous fuel in an oxidized atmosphere by ultra-acoustical effects.

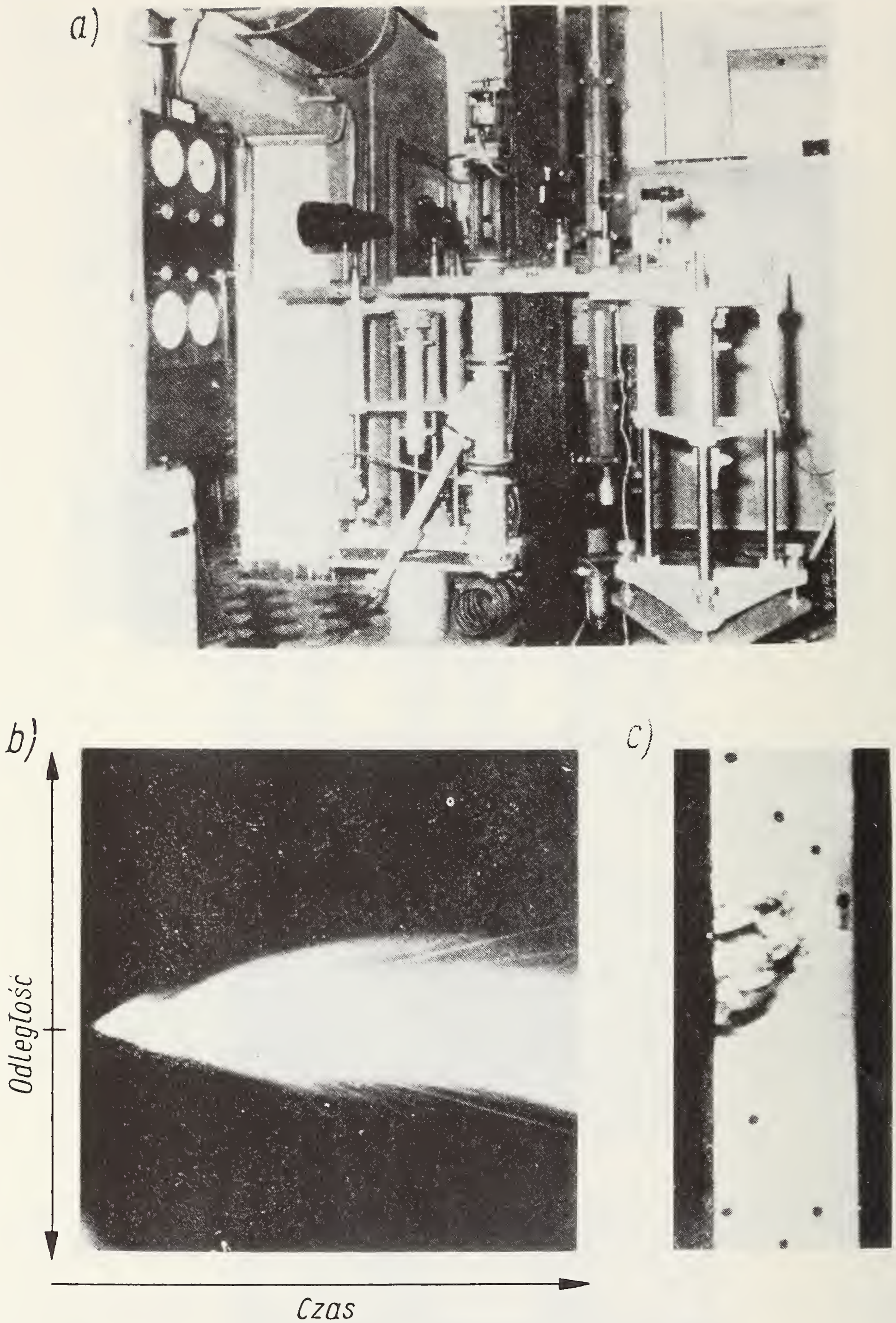

FIG. 16. Shock tube for investigating detonation in two-phase systems: a) view of the stand; b) scan photograph of two-phase combustion; c) frame of ignition in a two-phase system.

primarily for the study of detonation. These stands, which are used to study rapid processes (ignition, explosion, shock waves, detonation waves) are provided with measurement and photographic equipment for schlieren photography (cinematic and scanning) as well as gauges for measuring rapidly changing pressures and for determining the rate of propagation of detonation waves.

Three sample frames of schlieren photographs of gas-fuel ignition in an oxidizing atmosphere are given in Fig. 15b.

The other stand illustrated by the photographs in Fig. 16a is used to study two-phase detonation. It is a vertically mounted shock tube with a droplet generator (Fig. 16c) and at the bottom, a smaller auxiliary shock tube to produce shock waves in the main tube (to study their influence on the combustion process).

Figure 16b shows a schlieren scan of flame propagation in a mixture of drops of fuel and oxygen; Fig. 16c shows the ignition of such a mixture.

6. Direct Heating of Water

The direct heating of water by submerged burners is becoming more and more widely used in heating and chemical technology. The virtue of this method is simple boiler design and the high efficiency of the process. In the future, direct combustion in water will be employed as an energy source in water jet engines used for propulsion of fast naval units.

Research here is being carried out with three stands: a tunnel for the study of flames under water (Fig. 17) and experimental facilities for heating water by means of a submerged burner (Fig. 18a) and pulsating combustion (Fig. 18b).

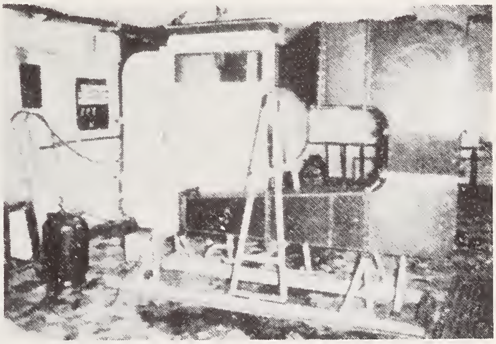

FIG. 17. Tunnel for the study of combustion processes in water.

The tunnel is being used to study the stabilization of oxygen—hydrogen flames in a water jet, behind a blunt body, the other facilities being used to find optimal operating parameters for such flames. The new element is the high operating pressure (of the order of several atmospheres), extending the range of usefulness of the method and increasing the efficiency.

In the other facility, a pulsating engine produces hot combustion gases. Its outlet is connected to a heat exchanger in which the combustion gases heat atomized water. The advantages of this system are the intense heat exchange (owing to the large contact surface area and the turbulence generated by the pulsating flow and that it is a simple, automatic system which does not require the use of an air compressor or a ventilator).

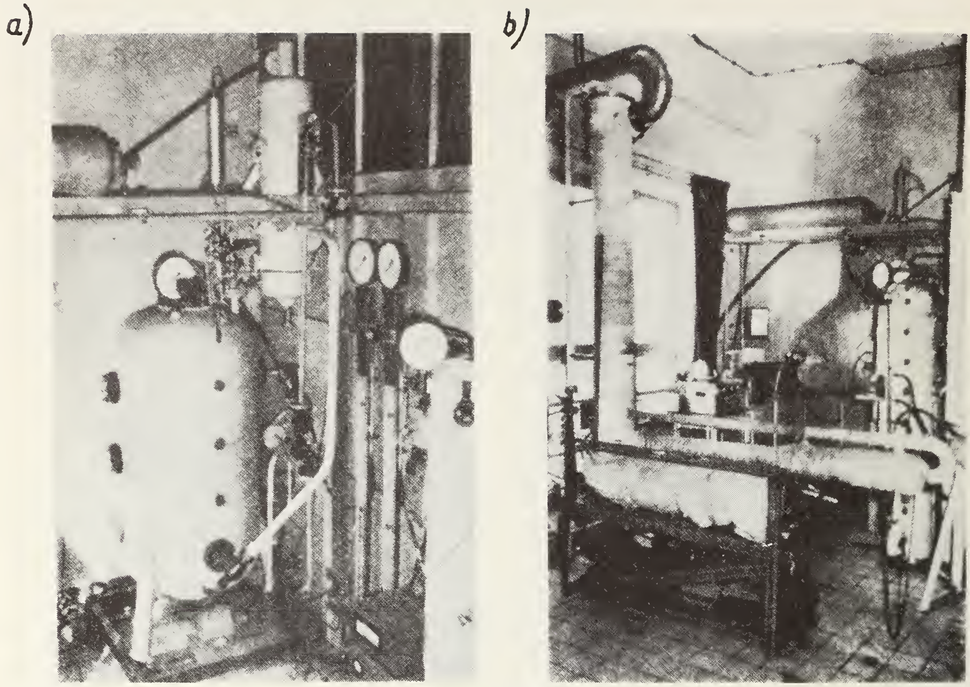

Fig. 18. Experimental equipment for direct heating of water: a) by means of a submerged burner; b) by means of pulsating combustion.

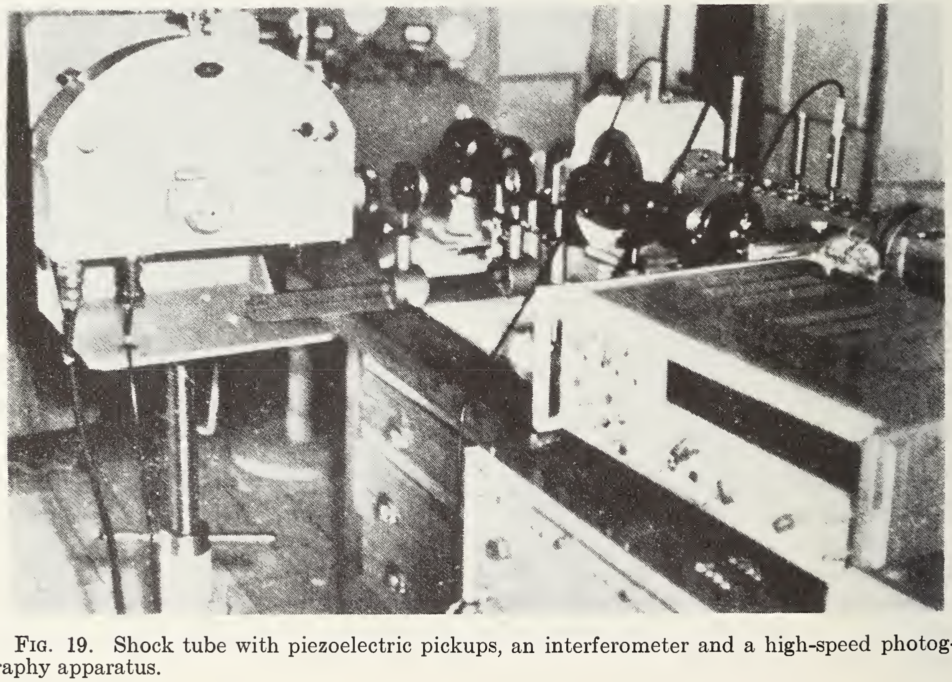

Fig. 19. Shock tube with piezoelectric pickups, an interferometer and a high-speed photography apparatus.

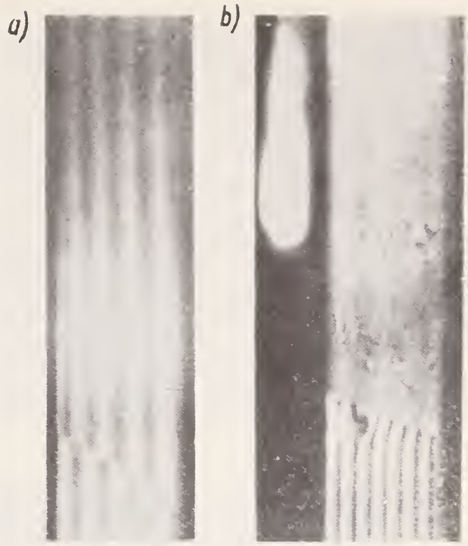

Fig. 20. Interferograms: a) incident and reflected waves without chemical reaction; b) ignition behind a reflected wave.

7. Measurement Techniques

For our scientific work to compete with foreign establishments, we must have comparable measurement instruments. It was difficult to handle highly variable processes under extreme conditions. Some of the devices, such as the microphotometer (Fig. 2), high-speed camera (one for 3,000, the other for 2.5 million pictures a second) and oscillographs were imported. Others, such as the chromatograph and some electronic instruments were bought on the market. The majority, however [e.g., the devices for schlieren photography (Figs. 14, 15a, 16a), the lasers (Figs. 14, 15a, 27) and the interferometer (Figs. 19, 20)] were made on our own premises with the cooperation of specialists from affiliated institutions (Aeronautics Institute, Polish Optical Institutes, Optics Department of the Warsaw Polytechnic, Physics Institute of the Warsaw Polytechnic, et al.). Our own workshops were extremely competent and cooperative in this undertaking.

Several unique measuring methods, such as measuring highly variable pressures by means of piezoelectric pickups (Fig. 21), highly variable temperatures by the spectral line inversion method (Fig. 22), the temperature distribution in a flame by the photographic method (Fig. 23), and the dust concentration by the photoelectric method (Fig. 24), were developed to meet the requirements of specific investigations.

8. Directions of Development of the Laboratory

The Laboratory is now rather well equipped with measurement apparatus and test stands. We can, therefore, carry out experiments in a broad range of research topics.

Our intentions are the study of combustion under extreme conditions, namely at very low and very high pressures, very high temperatures, and supersonic flow velocities as well as the effect of external fields on this process.

These intentions have been realized to a degree; Fig. 25 shows an automatic

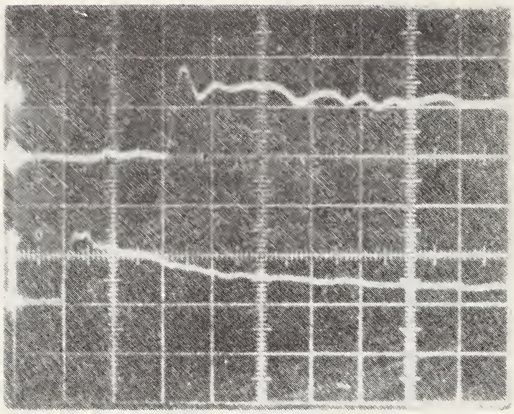

FIG. 21. Oscillograms of pressures measured by means of piezoelectric pickups.

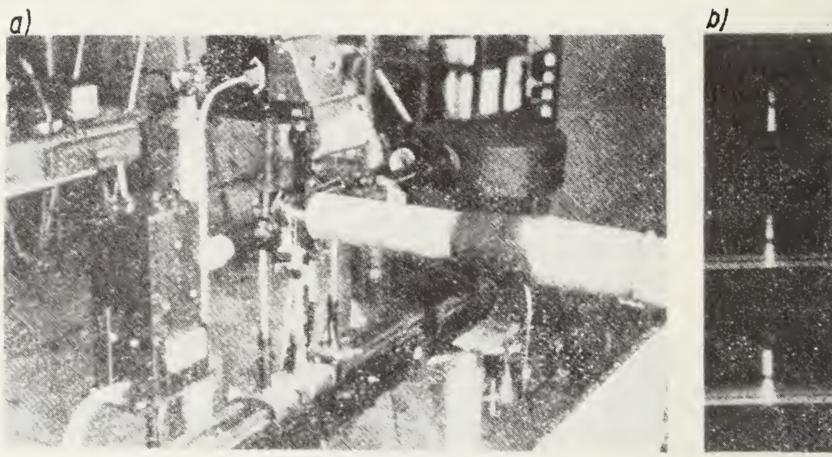

Fig. 22. Device for measuring highly variable temperatures by the spectral line inversion method: a) view of the setup; b) photographs of cross sections of the flame spectrum and a standard lamp filament.

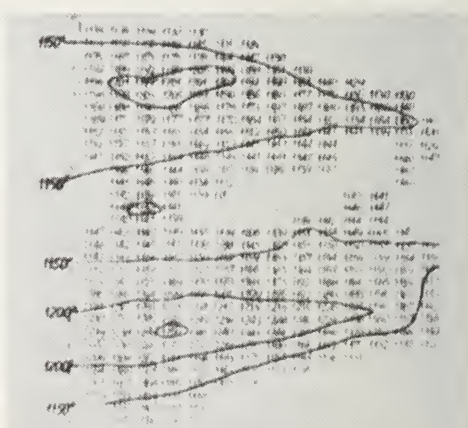

FIG. 23. Temporature distribution in the non-streamlined body, obtained by the photo stabilization zone for dust-air flame behind graphic method.

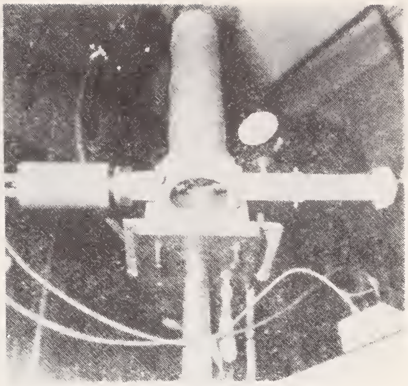

FIG. 24. Device for measuring the dust concentration in dust-air mixtures by the photo-electric method.

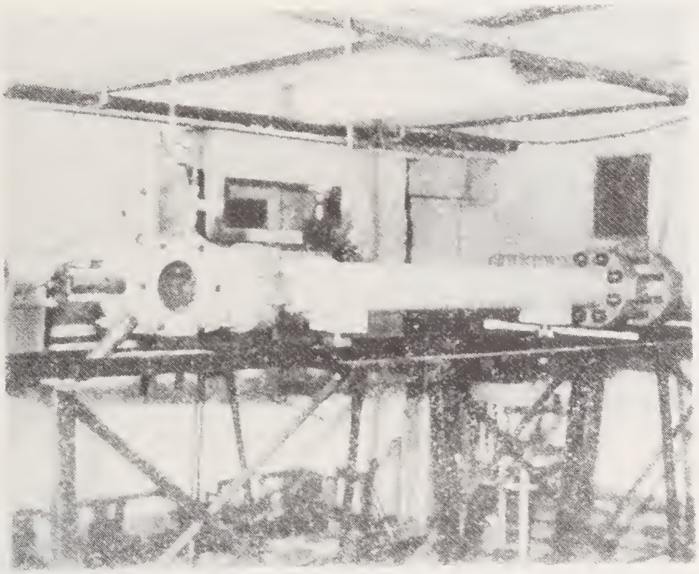

FIG. 25. Test stand for studying the combustion of two-phase mixtures at high temperatures and pressures.

setup for the study of two-phase mixtures at high temperatures (up to several thousand °C) and high pressures (up to 1000 bars). It uses isentropic gas compression (by means of a freely moving piston) provided by the pressure of the explosion.

Figure 26 shows an arrangement for investigating the effect of an electric field on the behavior of a flame.

The effect of laser radiation on the combustion process is studied using the arrangement shown in the photograph of Fig. 27. The effect of such radiation on the flame stabilization of gas mixtures in burners is being studied.

Other setups, e.g., shock tube with electromagnetic piston, shock tube designed for operation in a range up to 25,000 atm, a tunnel for the study of combustion in a plasma atmosphere, are in the design or construction stage.

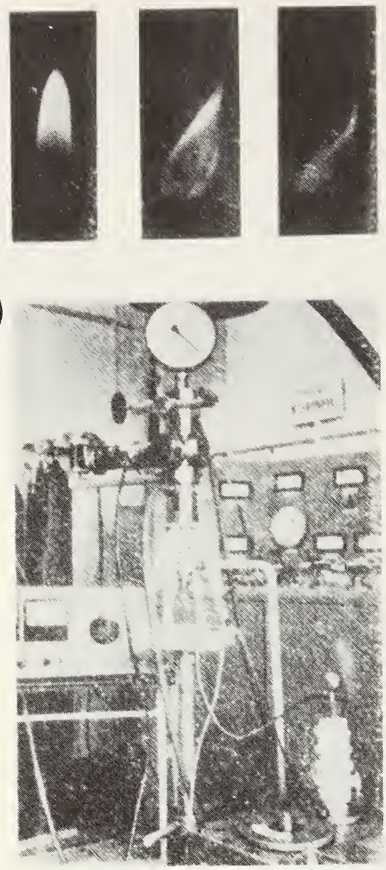

Fig. 26. Arrangement for the study of the effect of an electric field on combustion process.

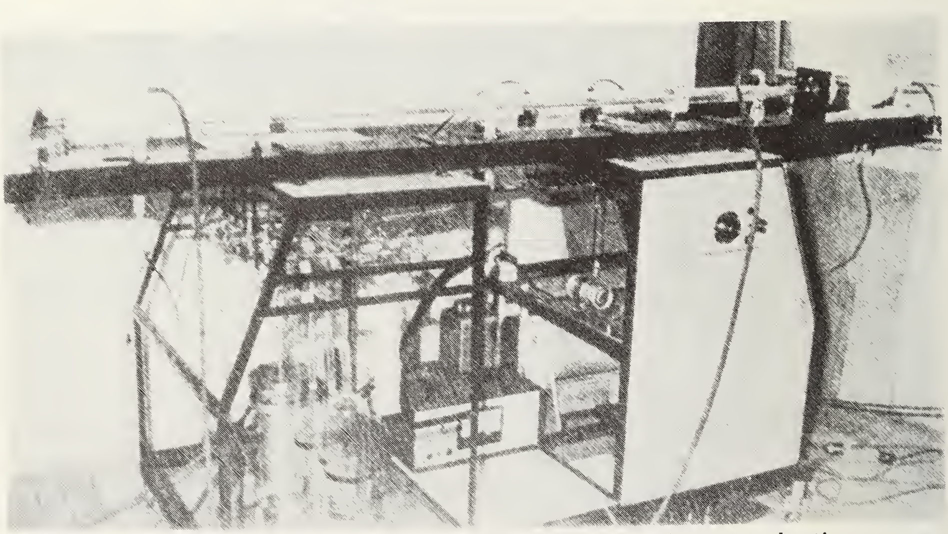

Fig. 27. Arrangement for the study of the effect of laser radiation on combustion process.

Summary

A characteristic feature of our Combustion Laboratory is the existence of mutually complementary research setups so that problems can be broadly treated and studied. The collaboration of the Laboratory with industry should be emphasized. Stabilization of the research program permits scientific personnel employed in the Laboratory to reach high qualifications and has allowed long-term contracts as well as our own participation in two research programs: the plan of the Aircraft and Engine Industry for research in the field of combustion in high-pressure engines and the plan of the Power Combine for research in the field of rotary coal-dust burners.

ABSTRACTS AND REVIEWS

A. Prevention of Fires, Safety Measures, and Retardants

Baldwin, R. and Thomas, P. H. (Joint Fire Research Organization, Borehamwood, Herts., England) "Passive and Active Fire Protection—The Optimum Combination," *Fire Research Note No. 963, Joint Fire Research Organization* (March 1973)

Subjects: Fire resistance; Fire protection; Sprinkler; Economics; Cost benefit; Passive fire protection; Active fire protection

Authors' Summary

It is argued that sprinklers and fire resistance can be used in combination, but as they serve different functions, they are not freely interchangeable. This note presents a model which shows how to trade off one against the other. The economic optimum combination is that which minimises the sum of costs and expected loss. A major cost parameter for fire protection systems is identified for which few data are available at present. A diagram is presented which shows the principle under which one system or the other is preferred in isolation, where a combination of systems is preferred, or where no protection is justified.

Bell, K. M. and Caesar, H. J. "The Influence of Chlorine on the Flame Resistance of Plastics," *Paper No. 14, Conference on Plastics in Fire,* I.E.E., London (November 1971)

Subjects: Plastics; Polymers; Fire resistance of plastics; Chlorine fire retardants

Reprint of Safety in Mines
Research Establishment Abstract,
By Permission

The various theories advanced to explain the role of chlorine-based fire retardants in increasing the flame resistance of plastics are reviewed, and both the mode of inclusion and the action of chlorine with synergists are discussed. Guide lines are drawn for selecting and evaluating chlorine-containing fire retardants. In order to illustrate the use and effectiveness of chlorinated fire-retardant additives, the formulation of high quality flame-resistant plasticised PVC compounds including chlorinated paraffin secondary plasticisers of the 'Cereclor' type is described. In flame-resistant PVC compounds chlorinated paraffin may be used with non-flammable phosphate plasticisers or alternatively with combinations of phthalate plasticisers and synergists such as antimony trioxide. Arising from the use of chlorinated paraffins, the properties of the compound may be enhanced with an attendant improvement in flame resistance. (9 refs., 2 figs., 10 tables.)

Palmer, K. N. (Joint Fire Research Organization, Borehamwood, Herts., England) "Dust Explosion Venting—Consideration of Further Data," *Fire Research Note No. 961, Joint Fire Research Organization* (March 1973)

Subjects: Dust explosion; Explosion venting

Author's Summary

Equations developed previously, which related the maximum pressure in a vented dust explosion to the properties of the dust and the geometry of the explosion vessel, have been checked against further experimental data, and their theoretical basis has been extended. The following industrial plant systems were considered: vent ducting, a cyclone, and relatively large vessels with small vents. Attention was also paid to maximum rates of pressure rise in closed vessels of different volumes.

The application of the equations to the plant systems was generally adequate and gave further insight into the processes involved in vented dust explosions. There is still a serious shortage of experimental data for dust explosion venting, requiring the continued use of unconfirmed basic assumptions.

Rogowski, Z. W. and Finch, C. P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Evaluation of Road Tanker Dip Tubes as Flame Barriers," *Fire Research Note No. 964, Joint Fire Research Organization* (March 1973)

Subjects: Flame arrester; Tanker; Explosion; Prevention; Test

Author's Summary

Dip tubes are used for liquid level measurements in the compartments of road tankers transporting fuel. They are fitted with flame arresters intended to eliminate the hazard of explosion originating outside the tanker from propagating within the tanker compartments. These arresters cover the necessary openings in the wall of the dip tubes and are designed to confine an accidental explosion within the tube. The performance of three dip tubes has been tested. One tube gave a satisfactory performance, the other two failed to stop the transmission of the explosion.

U.S. Forest Service, Fort Collins, Colorado and Marana, Arizona. "Computing Fire Danger Ratings: Programmed Instruction for the National Fire Danger Rating System," *TT-83(5100), U.S. Forest Service, Department of Agriculture,* Washington, DC (July 1972)*

Subjects: Fire danger ratings; Forest fires; Ratings of fire danger

B. Ignition of Fires

Cullis, C. F. and Foster, C. D. (The City University, London, England) "Studies of the Spontaneous Ignition of Hydrocarbons and the Application of Computer Techniques," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 423 (1973)

* Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Subjects: Ignition of hydrocarbons; Spontaneous ignition; Hydrocarbons, ignition of; Computer model of ignition; Cool flames; Two-stage flames; Flames, two-stage and cool

Authors' Abstract

Measurements have been made of the ignition limits of *n*-decane–air mixtures, both in empty spherical vessels and in spherical vessels with heated tubes of different diameter passing through the center. It has been shown that thermal-ignition theory gives a good explanation of the variation with mixture composition at a fixed pressure of the minimum temperature required for spontaneous ignition. Furthermore, it provides a good description of the way in which the boundary separating slow combustion from cool flames and two-stage ignition varies with initial temperature and pressure. A computer program has been devised on the basis of the above application of thermal-ignition theory to the experimental results. This makes it possible to predict the spontaneous-ignition limits in a spherical vessel of a given alkane, the only information required being the radius of the vessel, the molecular structure of the alkane, and the nature of the oxidant. By use of this program, the temperature limits for ignition in a spherical vessel containing heated tubes of known diameter may be estimated for given alkanes.

Gurevich, M. A., Ozerova, G. E., and Stysanov, A. M. (Leningrad, U.S.S.R.) "Critical Conditions of Self-Ignition of a Poly-Dispersed Gas Suspension of Solid-Fuel Particles," *Fizika Goreniya i Vzryva* **7**(1), 9–19 (March 1971) (In Russian)

Subjects: Self-ignition; Ignition; Particles; Suspension; Solid-fuel particles; Dust clouds; Limits of ignition

Authors' Conclusions
Translated by L. Holtschlag

A theoretical analysis is made of simplified configurations of the fuel ignition process in order to permit calculation of critical self-ignition conditions for a poly-dispersed suspension of particles in a gas, under the following assumptions:

1. Chemical reaction occurs only on the surface of the particles; the dependence of the reaction rate on the temperature and oxidizer content is described by the Arrhenius formula;
2. The heat liberated during reaction is transmitted outward to the walls by the gas surrounding the particles. The gas temperature at any instant is the same over the whole volume.
3. Mass transfer between the gas suspension and the outer medium is absent, and the oxidizer concentration is uniform over the entire volume at any given time.
4. The particles are spherical, constant in size and without a temperature gradient. Particles of each size are uniformly distributed in the gas volume.
5. The gas density, specific heat and thermal-conductivity coefficient are constant. Ignition limits are obtained for a gas suspension of particles consisting of two fractions and for a suspension with a continuous size distribution of particles.

Kocherga, N. G. "Igniting Capability of Frictional Sparks Formed during Rock Crushing," *Bezopas. Truda Prom.* **17**(4), 48–50 (in Russian) and *Safety in Mines Abstracts* **21**, 1005 (1973)

Subjects: Ignition; Sparks; Rock spark ignition; Frictional sparks

Safety in Mines Research Establishment
Abstract, by Permission

The method and apparatus used for determining igniting capability and the nature of frictional sparks formed during rock crushing is described. The tests showed that sparks emitted during impact of various metals (steel, bronze, etc.) against sandstone, ignite 6–6.5% air-methane mixture. It was, nevertheless, found that a normal water spraying during crushing of pyrite inhibits ignition of methane. (2 figs., 2 tables.)

Rae, D. (Department of Trade and Industry, Safety in Mines Research Establishment, Buxton, England) "Initiation of Weak Coal-Dust Explosions in Long Galleries and the Importance of the Time Dependence of the Explosion Pressure," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1225 (1973)

Subjects: Initiation of explosions; Ignitions; Coal-dust ignition; Dust explosions; Explosions of coal dust; Time dependence of explosion pressure; Pressure of explosion

Author's Abstract

Weak coal-dust explosions in galleries (large horizontal tubes) are defined in the paper as the early stages of what may eventually become a self-sustaining, steady-state situation, if the scale is large enough. An initiating explosion producing a pressure rise of at least 12 kPa is needed to start an explosion from any additional dust that lies beyond the initiating zone; entrainment of this additional dust leads to the main explosion. In long galleries, initiating explosions in the range 16 ± 2 kPa are mostly used. The early stages of the main explosion resemble explosions in which combustion of a very low concentration of coal-dust particles is taking place over a considerable volume at any given time, rather than explosions in which a flame, having a more or less definable front and rear, is propagating through a preformed explosive mixture. The explosions are described in terms of the general shape of the pressure changes occurring at a point near the outermost extent of the flame that is produced by the initiation explosion alone. The initial pressure rise is determined by the form of the initiating explosion and is followed by a roughly exponential pressure increase (from atmospheric pressure), whose time constant depends on the nature of the coal-dust, its dispersion, and the dimensions and characteristics of the gallery. The effects on the development of the explosion of the presence of short dust deposits, suppressive devices, and the ignition of predispersed clouds are briefly discussed. It is concluded that, in weak explosions, propagation results from dust being swept from the floor into the zone of combustion behind the flame front. However, as pressures increase to above, say, 100 kPa, other mechanisms become responsible and, perhaps, a pre-detonation regime sets in.

Wolanski, P. and Wójcicki, S. (Warsaw Technical University, Warsaw, Poland) "Investigation into the Mechanism of the Diffusion Ignition of a Combustible Gas Flowing into an Oxidizing Atmosphere," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1217 (1973)

Subjects: Ignition by shock; Diffusion flame ignition

Author's Abstract

The emission of a combustible gas into a region filled by a gaseous oxidizer generates a pressure wave which can cause ignition under certain conditions, even if the overall temperature of the gas is below the ignition temperature.

Based on the experimental results obtained and on theoretical analysis, it was found that ignition is caused by an increase in the temperature of the combustible mixture produced by diffusion, due to the heat flux from the oxidizer which has been heated in a shock wave. This phenomenon is referred to in the present paper as a *diffusion ignition.*

The mathematical model established for this process makes it possible to determine the critical conditions for the occurrence of such an ignition. Computation showed that diffusion ignition of synthesis gas, used for the production of ammonia, is possible at a temperature of 575°K, i.e., below its normal ignition temperature of 655°K, if the Mach Number of the shock wave exceeds 2.8. This result has been confirmed experimentally, by means of schlieren frame photographs.

C. Detection of Fires

Fardell, P. J. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Performance of Some Portable Gas Detectors with Aviation Fuel Vapours at Elevated Temperatures. Part 2: Tests with 'Avcat,' 'Kero B,' and 'Avtur' Vapours," *Fire Research Note No. 957, Joint Fire Research Organization* (January 1973)

Subjects: Flammable gas; Tests; Detector

Author's Summary

The results of further tests on portable flammable gas detectors are given. The response of these detectors was low when they were operated at 65°C ambient temperature and at moderate humidity levels with the aviation fuels 'Avcat,' 'Avtur' and 'Kero B.'

O'Sullivan, E. F., Sumner, R. L., Ghosh, B. K., and Smith, P. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Detection of Fires by Smoke. Part 5: Development of a Smoke Tunnel for Testing Fire Detectors," *Fire Research Note No. 822, Joint Fire Research Organization* (January 1973)

Subjects: Detector; Fire; Smoke; Specification; Particle size, smoke

Author's Summary

A laboratory-bench scale method for measuring the sensitivity of smoke detectors is desirable. To be of value, the laboratory test must be capable of predicting the response of a smoke detector to real fires. This Note discusses how far this requirement can be met with a smoke tunnel (0.63 m^3 volume) of simple construction. Experiments are described which simulated, in the tunnel, an important phenomenon observed in full-scale fire tests, namely, the dependence of the response of an ionisation-chamber smoke detector on the age of the smoke.

Some suggestions for future work directed towards improving the tunnel are made.

D. Propagation of Fires

Harmathy, T. Z. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "A New Look at Compartment Fires, Parts I, II," Fire Technology **8,** 196–217, 326–351 (1972) See **Section G.**

Kogarko, S. M. and Ryabikov, O. B. (Moscow, U.S.S.R.) "Determination of the Concentration Limits of Flame Propagation in Hydrogen—Oxygen Mixtures in the Initial Pressure Range of 1 to 100 Abat," *Fizika Goreniya i Vzryva* **6**(3), 406–407 (September 1970) (In Russian)

Subjects: Burning velocity; Limits of propagation; Pressure dependence of burning velocity; Hydrogen—Oxygen

Authors' Conclusions
Translated by L. Holtschlag

The studies were carried out at a temperature of 20°C in a spherical steel reaction vessel with a diameter of 160 mm and a test volume of 2,100 cm^3, evacuated to 10^{-2} mm Hg. A nichrome wire in the center of the vessel ignited the mixture via discharge from a battery of condensers. The flame propagation was recorded by a pressure indicator provided with a set of sensors. The signal from the pressure indicator was transmitted to the input of an oscilloscope for visual observation of the pressure rise. The mixture was considered to be dangerous if a significant pressure increase was recorded. The results are presented in graphic form as the dependence of the concentration limits of flame propagation on the pressure. The curves show upper and lower limits. The lower limit varied gradually from 4.5% H_2 at 1 abat to 6.0% H_2 at 50 abat, remaining constant up to 100 abat.

Romodanova, L. D., Pepekin, V. I., Apin, A. Y., and Pokhil, P. F. (Moscow, U.S.S.R.) "Relationship between the Burning Velocity of a Mixture and the Chemical Structure of the Fuel," *Fizika Goreniya i Vzryva* **6**(4), 419–424 (December 1970) (In Russian)

Subjects: Burning velocity; Chemical structure of fuels; Ammonium perchlorate

Authors' Conclusions
Translated by L. Holtschlag

A study is made of the burning rate of mixtures with an ammonium perchlorate base and a fuel containing various functional groupings. The heating capacity of these compounds was determined experimentally. The experimental value of the burning rates was considered from the viewpoint of the heating capacity of the compounds and the strength of the chemical bonds of the fuel. The following classes of organic compounds were used as fuels: monobasic and dibasic unsaturated acids, saturated fatty acids, aromatic hydrocarbons, amines, nitramines, polynitro compounds and organometallic compounds. Stoichiometric compounds with APC were prepared with these fuels. The compounds were compressed in a 5 mm-diameter mold to maximum density. The particle size of the APC was less than 100μ. The compounds were ignited in a bomb under nitrogen pressure, the burning rate was determined by a photorecorder. The heating capacity was determined in a calorimeter arrangement with a heat equivalent of 2,702.6 $\pm$ 1.1 cal/deg. The results indicate that the burning rate does not depend on the calorific value of the compound, but is governed by the strength of the weakest bond in the fuel molecule.

Thomas, P. H. (Joint Fire Research Organization, Borehamwood, Herts., England) "On the Rate of Burning of Cribs," *Fire Research Note No. 965, Joint Fire Research Organization* (March 1973)

Subjects: Crib; Burning Rate; Wood

Author's Summary

This paper discusses the rate of burning of wood cribs and the comparison between the data of O'Dogherty and Young and Webster, and a theoretical model having much in common with Block's. It is suggested that the source of a discrepancy between the data and Block's original theory is the over-simplification of an averaging procedure for the mass transfer process and the use of the Reynolds analogy. Difficulties remain with describing the pyrolysis process and the mixing of the fuel and air in the crib shafts which preclude too exacting a comparison between present theories and currently available data.

E. Suppression of Fires

Benson, S. P., Morris, K., and Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "An Improved Method for Measuring the Drainage Rate of Fire-Fighting Foams," *Fire Research Note No. 972, Joint Fire Research Organization* (May 1973)

Subjects: Foam; Drainage; Tests

Authors' Summary

The 25 per cent drainage times of fire-fighting foams have hitherto been determined using a 1400 ml pan, 1.87 cm dia x 5 cm deep (7⅜ in. x 2 in.). This method was shown to have a low level of reproducibility when testing foam from a 5 l/min (1.1 gal/min) branchpipe. It was found that the sample size must be related to the flow rate of the foam stream being tested, and to its uniformity. Details of a new 6320 ml drainage pan, 20 cm dia x 20 cm deep (7.9 in. x 7.9 in.) are given, which is suitable for testing foam from a 5 l/min branchpipe. The 25 per cent drainage time was found to be independent of pan diameter but changed with pan depth. Details of a new 1630 ml drainage pan, 10 cm dia x 20 cm deep (3.9 in. x 7.9 in.) are given, which gives the same drainage time as the 6320 ml pan, and is suitable for testing foam from a laboratory generator at 0.75 l/min (0.1 gal/min). It is recommended that 25 per cent drainage times should always be measured in a pan of this depth, to give comparable results between laboratories.

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (Pittsburgh Mining and Safety Research Center, U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Flame-Structure Studies of CF_3Br-Inhibited Methane Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 367 (1973) See **Section G.**

Combourieu, J., Le Bras, G., and Paty, C. (Centre de Recherches sur la Chimie de la Combustion et des Hautes Températures et Faculté des Sciences d'Orléans, Orléans, France) "Reaction of H Atoms with CH_2Cl_2 Application to the Inhibition of Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 485 (1973) see **Section H.**

Griffiths, D. J. (Joint Fire Research Organization, Borehamwood, Herts., England) "A Laboratory Burn-Back Test for Fire-Fighting Foams," *Fire Research Note No. 975, Joint Fire Research Organization* (June 1973)

Subjects: Foam; Burn-back; Compatibility Test; Tests for foams

Author's Summary

This note describes the development of a laboratory-scale burn-back test. The effects of changes in the properties of the foam on its burn-back resistance have been investigated and the results used to produce a standard test method.

This method has been used to compare eight commercially available foam liquids and to determine the compatibility of fluorochemical and protein foams with reference to their burn-back resistance.

Ksandopulo, G. I., Kolesnikov, B. Ya., Zavadskii, V. A., Odnorog, D. S., and Elovskaya, T. P. (Alma Ata, U.S.S.R.) "Mechanism of the Inhibition of Combustion of Hydrocarbon—Air Mixtures by Finely Dispersed Particles," *Fizika Goreniya i Vzryva* **7**(1), 92–99 (March 1971) (In Russian)

Subjects: Flame structure; Inhibition; Powder inhibitors; Potassium iodide; Hydrocarbon flames; Propane—air flame structure

Authors' Summary
Translated by L. Holtschlag

Samples taken from the flame by a quartz microsampler are analyzed with a mass spectrometer to determine the profiles of compositions of stable particles in the combustion zone of a propane–air mixture inhibited by a potassium iodide mixture. The premixed propane–air flame was produced in a glass burner with an outer diameter of no more than 0.35 mm and a length of 8 mm. The potassium iodide inhibitor was in the form of powdered particles 0.006 to 0.008 mm in size; the amount introduced was 0.5 mg/l. The results of the analysis are presented in the form of graphs giving the dependence of the concentration of various components in the flame gases on the distance along the normal to the flame front. It is established that the process of inhibition by solid particles reduces to the accelerated formation of formaldehyde as well as to the deceleration of the decrease of formaldehyde by recombination of the OH radical on the surface of the solid particles. The variation in the efficiency of inhibition is proportional to the total surface area of the particles and is a function of the nature of the particles, which is a proof of the heterogeneous mechanism of deceleration of combustion.

Pagni, P. J. and Peterson, T. G. (University of California, Berkeley, California) "Flame Spread through Porous Fuels," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1099 (1973)

Subjects: Flame spread rate; Porous fuels, flame spread in; Fuels, porous

Authors' Abstract

A quantitative analysis of the steady-state propagation of a quasi-one-dimensional flame through a thermally thin, porous layer of fuel is presented. The rate of energy transfer from the combustion zone to the fuel is assumed to control the rate of flame propagation. Energy-transfer mechanisms considered are flame and ember radiation, surface and internal convection, turbulent diffusion of flame eddies, and gas-phase conduction. The effects of ambient flow, fuel moisture, fuel-bed slope, and endothermic pyrolysis are included. A nondimensional flame-spread velocity is obtained as a function of nondimensional fuel, flame, and ambient flow properties. It is found that, in the case of ambient flow in the direction of flame propagation, the flame-spread velocity increases rapidly as the ambient flow velocity increases. From model predictions for a moderately porous fuel, typical of pine-needle beds, the following conclusions are drawn: (1) with no ambient flow, the dominant preheating mechanism is flame radiation, with contributions from ember radiation and gas-phase conduction; (2) for most nonzero ambient flow velocities, the primary mechanism is convection with a significant contribution from flame radiation; (3) energy transferred by turbulent flame eddies appears to be generally negligible; and (4) energy absorbed by pyrolysis, prior to ignition, is negligible. Excellent quantitative agreement with experiment has been obtained. More rigorous analytical models may be formulated, based on the relative import of the energy-transfer mechanisms indicated here. Applications are discussed.

F. Fires, Damage and Salvage

G. Combustion Engineering and Tests

Adams, J. S., Williams, D. W. (Australian Defence Scientific Service, Defence Standards Laboratories, Melbourne, Victoria, Australia), **and Tregellas-Williams, J.** (Department of Defence, Canberra, Australia) "Air Velocity, Temperature, and Radiant-Heat Measurements Within and Around a Large Free-Burning Fire," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1045 (1973)

Subjects: Euroka fire; Australian fire; Mass fires; Air velocity around a mass fire; Temperatures in mass fires; Radiant energy fluxes from a mass fire

Authors' Abstract

Operation Euroka was a 210,000 m^2 (50 acres) free-burning mass fire experiment carried out in Queensland, Australia. At the peak of the fire, 42 min after ignition, the maximum average induced horizontal wind velocity at the edge of the fire was 4.2 m/sec. The fire was of relatively low intensity, with a peak convective heat-release rate of 2.0×10^{10} W and a peak radiant energy-release rate of 4×10^9 W.

The ratio of the radius of the projection of the conical portion of the convection plume onto the surface to the radius of the fire bed was only 0.18, compared with the value of 0.4 reported for the more intense Flambeau fires. Consequently, this ratio may be a function of the fire intensity. If this is so, then, for a fire of a given size, the induced inflow wind velocity is a stronger function than the cube root of the heat-release rate.

Akita, K. (University of Tokyo, Bunkyo-ku, Tokyo, Japan) "Some Problems of Flame Spread along a Liquid Surface," *Fourteenth Symposium (International)* *on Combustion,* The Combusion Institute, Pittsburgh, Pennsylvania, p. 1075 (1973)

Subjects: Flame spread on liquids; Liquids, flame spread across; Surface tension and flame spread; Margolous effect

Author's Abstract

Recent studies of flame spread along a liquid surface were surveyed. It is clear that the flame spread in the temperature region below the flash point of fuel is mainly controlled through the liquid flow caused by surface tension and buoyancy force, as suggested by Roberts, Glassman, and others. However, since a region where no surface flow is observed and a particular behavior of pulsating flame spread are also found for alcohol fuels, the phenomena in question do not seem to be as simple as previously thought. In this paper, flame spread is classified into three groups of uniform, pulsating, and pseudo-uniform spread, depending on the temperature of the liquid, and the mechanism of flame spread in each region is discussed in the light of new experimental results.

Andrews, G. E. and Bradley, D. (Department of Mechanical Engineering, The University, Leeds, England) "Limits of Flammability and Natural Convection for Methane—Air Mixtures," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1119 (1973)

Subjects: Flammability limits; Limits of flammability; Convection effect on flammability; Methane—air flammability limits

Authors' Abstract

The existing methods of measuring the limits of flammability are critically reviewed. Experimental results are presented that were obtained with a cylindrical vessel equipped with windows. Flame propagation was recorded using a laser source, schlieren-interferometric techniques, and a high-speed camera. Gas velocities ahead of the flame front were measured with a hot-wire anemometer. These techniques also provided information on hot-gas kernels produced by the spark, but with no flame propagation. Limits of flammability were observed for upward and downward propagation, and burning velocities in near limit flames were measured, together with hot-gas convective rise velocities.

A theory is developed for the effects of natural convection, in which the buoyancy force acting on the hot kernel is equated to the kernel's rate of change of momentum. The reasons for the neglect of drag in the early stages are discussed. The theory gives the time for the top of the flame to move a given distance, and the convective rise velocity. There is fair agreement with the experimental results.

The role of natural convection in determining the limit for downward propagation is discussed. The limit for upward propagation is discussed in terms of wall quenching, gas-phase quenching, and initial failure to ignite the mixture.

Beyreis, J. R., Monsen, H. W., and Abbasi, A. F. (Fire Protection Department, Underwriters' Laboratories, Inc.) "Properties of Wood Crib Flames," *Fire Technology* 7, 145 (1971) See **Section I.**

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (Pittsburgh Mining and Safety Research Center, U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Flame-

Structure Studies of CF_3Br-Inhibited Methane Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 367 (1973)

Subjects: Flame structure; Inhibition of flames; CF_3Br; Methane flame, inhibited

Authors' Abstract

Low-pressure flat flames have been probed with a molecular-beam sampling system coupled to a modulated-beam mass spectrometer. The purpose of the study it to determine and compare the microstructure of normal CH_4–O_2–Ar flames, and those inhibited by CF_3Br, in order to provide some basis for an understanding of how inhibition is effected in this system. The experimental facility is new and is described in some detail. Composition profiles of slightly lean, uninhibited flames were obtained for the major stable species (CH_4, O_2, CO, CO_2, H_2O) and H_2 and H_2CO. Sampling at low electron energies gave, with appropriate corrections, a profile for the 17^+ peak which is assigned to hydroxyl radical. Profiles were also determined for a CH_4–O_2–Ar flame containing 0.3% CF_3Br. In addition to the usual flame species, the inhibitor, its products, and intermediates associated with its reactions could be followed. In particular, HBr and Br atoms could be followed; hydrogen fluoride and carbonyl fluoride were also observed. The inhibited flame is characterized by an early disappearance of inhibitor and correspondingly early appearance of products due to its reaction. Carbonyl fluoride and HBr behave like intermediates. Hydrogen fluoride and bromine atoms are the primary equilibrium flame products to be associated with the inhibitor. The immediate appearance of fluorinated species suggests a short lifetime for the CF_3 radical in this system, and the observation of carbonyl fluoride suggests that this inhibitor is effective, at least in part, by virtue of its interference with the oxygen-containing species of the normal chain mechanism.

Butler, C P., Martin, S. B., and Wiersma, S. J. (Stanford Research Institute, Menlo Park, California) "Measurements of the Dynamics of Structural Fires," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1053 (1973)

Subjects: Building fires; Fires in buildings; Dynamics of structural fires; Structural fires; Burning rate of buildings; Radiant flux from building fires; CO concentrations in building fires; Flashover

Authors' Abstract

Experiments in which wood-frame buildings are burned were conducted to determine the dynamic characteristics of one type of structure.

The burning rate, as measured by the weight-loss rate, was found to have a pulse shape similar to the pulse of radiant energy emitted during the fire. Radiant-flux levels surrounding the burning structures were well correlated with photographically estimated flame areas, through the Stefan–Boltzmann relationship.

Carbon monoxide concentrations and air temperatures reached lethal levels at about the same time in these burning buildings, usually corresponding to a point just prior to flashover of the compartment.

The results of this work offer encouragement to attempts at generalizing some of the dynamic characteristics of structural fires.

Canada, G. S. and Faeth, G. M. (Department of Mechanical Engineering, Pennsylvania State University, University Park, Pennsylvania) "Fuel Droplet Burning Rates at High Pressures," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1345 (1973)

Subjects: Fuel droplets; Droplets of fuel; Pressure (high) burning rate of fuel droplets; Burning rate of droplets

Authors' Abstract

Combustion of methanol, ethanol, propanol-1, *n*-pentane, *n*-heptane, and *n*-decane was observed in air under natural convection conditions, at pressures up to 100 atm. The droplets were simulated by porous spheres, with diameters in the range 0.63–1.90 cm. The pressure levels of the tests were high enough so that near-critical combustion was observed for methanol and ethanol. Measurements were made of the burning rate and liquid-surface temperatures of the fuels. The data were compared with variable property analysis of the combustion process, including a correction for natural convection. Due to the high pressures, the phase-equilibrium models of the analysis included both the conventional low-pressure approach as well as high-pressure versions, allowing for real gas effects and the solubility of combustion product gases in the liquid phase. The burning-rate predictions of the various theories were similar, and in fair agreement with the data. The high-pressure theory gave the best prediction for the liquid-surface temperatures of ethanol and propanol-1 at high pressure. The experiments indicated the approach of critical burning conditions for methanol and ethanol at pressures on the order of 80–100 atm, which was in good agreement with the predictions of both the low- and high-pressure analysis. Critical burning conditions could not be approached for the remaining fuels because of the formation of soot deposits on the sphere at pressures in the range 30–60 atm.

Eberius, K. H., Hoyermann, K., and Wagner, H. Gg., (Institut für Physikalische Chemie der Universität, Göttingen, West Germany) "Structure of Lean Acetylene—Oxygen Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 147 (1973)

Subjects: Flame structure; Acetylene—oxygen flame structure; Energy flux in flames; Kinetics of acetylene flames

Authors' Abstract

Premixed lean C_2H_2–O_2 flames, burning at reduced pressures (76 and 10.6 torr), were investigated to establish the mechanism of formation of the main reaction products (H_2O, CO, CO_2) at low final temperatures (960 and 1300°K).

The concentration profiles of the stable products were determined by mass spectrometry and gas chromatography and by ESR spectroscopy for the atoms (H, O). The OH concentration was determined independently by uv spectroscopy.

Calculation of the energy flux shows that the temperature rise in the preheating zone is caused by heat conduction (40%) and by energy transport via radicals (50%), mostly H atoms.

The removal of C_2H_2 occurs to a lesser extent by

$$OH + C_2H_2 \rightarrow CO + CH_3$$

but mainly via

$$O + C_2H_2 \rightarrow CO + CH_2.$$

For the early stage of flame, the formation of CO_2 is described by the over-all reaction

$$CH_2 + O_2 \rightarrow CO_2 + 2\,H$$

and, at the end of main reaction zone, via

$$CO + OH \rightarrow CO_2 + H.$$

Calculations of the mass fluxes from the measured profiles show that water is produced in different ways with varying efficiency: $OH + H_2 \rightarrow H_2O + H$ ($<6\%$), via CH_3 ($<15\%$), and in the main channel, $OH + OH \rightarrow H_2O + O$ ($>50\%$).

Forest Products Laboratory, Madison, Wisconsin. "Correlation of ASTM Exposure Tests for Evaluating Durability of Fire-Retardant Treatment of Wood," *U.S.D.A. Forest Service Research Paper FPL 194* (1973) See **Section M.**

Forest Products Laboratory, Madison, Wisconsin. "FPL Facility for Evaluating Strength-Performance of Walls Exposed to Fire," *U.S.D.A. Forest Service Research Paper FPL 199* (1973) See **Section M.**

Gerstein, M. and Stine, W. B. (Mechanical Engineering Department, University of Southern California, Los Angeles, California) "Analytical Criteria for Flammability Limits," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1109 (1973)

Subjects: Flammability limits, analytical criterion; Flame theory of limits; Limits of flammability

Authors' Abstract

The one-dimensional laminar flame equations with single-step Arrhenius kinetics, including both conduction and radiation heat loss to the surroundings, have been integrated. Adiabatic and nonadiabatic burning velocity, quenching distance, and an "apparent" flammability limit are calculated. It is shown that a fundamental flammability limit, independent of heat loss, does not exist even when radiation loss is included. The experimentally observed flammability limits are explained on the basis of the insensitivity of the critical fuel concentration for flame propagation to changes in tube diameter, when the radiation loss exceeds conduction loss. Flame thickness and inflection temperature are discussed as other possible criteria for "apparent" flammability limits. It is pointed out that safety criteria, based on flammability limits, should take into account the possible reduction of limits for very large systems.

Comparison is made with experimental values, in which pressure and diluent type and concentration are varied.

Gollahalli, S. R. and Brzustowski, T. A. (Department of Mechanical Engineering, University of Waterloo, Waterloo, Ontario, Canada) "Experimental Studies on the Flame Structure in the Wake of a Burning Droplet," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1333 (1973)

Subjects: Flame structure of droplets; Droplet flame structure; Wake of burning droplets

Authors' Abstract

Droplets burn in envelope flames at low approach velocities and in wake flames at high velocities. Detailed measurements on pentane burning on a porous sphere have shown that the wake portion of the envelope flame is quite different from the wake flame. The former has a near wake of a few diameters, which resembles a gaseous laminar diffusion flame, followed by a long far wake in which soot burns. The latter has a short near wake which is similar to the flame zone behind a flame holder, except for the lack of a recirculation zone, followed by a short zone of soot combustion. The burning rate for the envelope flame is about three times greater than the wake flame at a slightly higher approach velocity. Peak temperatures are about 1400°–1500°K, located near the droplet in the wake flame, but in the far wake in the envelope flame. Radiation from envelope flames is far greater than from wake flames; peak emittances are in the ratio of about 3.5 to 1. The contribution of soot to droplet flame radiation is negligible in the near wake, and approaches gas radiation in the far wake. Peak soot concentrations in the envelope flame are more than three times greater than in the wake flame.

Harmathy, T. Z. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "A New Look at Compartment Fires, Parts I, II," Fire Technology **8,** 196–217, 326–351 (1972)

Subjects: Compartment fires; Fires in enclosures; Pyrolysis; Toxic fire gases Wood fires; Building fires

Author's Abstract

This paper represents an effort to arrange available information concerning compartment fires into a consistent theoretical framework.

In the first few chapters some basic characteristics of the burning of cellulosic materials are surveyed. The two phases of burning (namely, pyrolysis and the combustion of pyrolysis products) are examined, and a model is proposed to describe the burning of piles of wood in an unconfined atmosphere. Some important differences between wood fires and liquid fuel fires are pointed out in order to explain contradictory views with regard to the sizes of flame.

A simple theoretical model is used as a common basis for two equations that describe the rate of burning in two different regimes of compartment fires, the fuel-surface-controlled and ventilation-controlled regimes. In subsequent chapters equations are derived for the size of flames in compartment fires, the heat evolved within the compartment, and the duration of fully developed fire. Proofs are provided that fuel-surface-controlled fires rarely last longer than 30 min, irrespective of the fire load.

The parameters of fire severity are discussed. Three parameters are selected to characterize the severity of fires: the duration of fully developed fire, the effective heat flux (available for absorption by the elements of compartment), and the average gas temperature. Equations are derived for these parameters and with their aid many experimental data are analyzed. In this connection complete energy balances are obtained for burning compartments which indicate that normally only a relatively small portion of the chemical energy of fuel is absorbed within the compartment.

Further theoretical studies point to the importance of deliberate design in reducing fire losses, as opposed to stereotyped protective measures. Some basic rules of correct compartment design are discussed. It is shown that, by properly selecting the ventilation openings, even unprotected steel structures can be safely employed in buildings.

The temperature history of gases in a burning compartment is formulated in an idealized way and compared with experimental data. Subsequently, the possible need for considering the decay period of fire in theoretical studies is discussed.

The paper concludes by emphasizing the urgent need for reviewing the current philosophy of fire protection of buildings.

Kogarko, S. M. and Ryabikov, O. B. (Moscow, U.S.S.R.) "Determination of the Concentration Limits of Flame Propagation in Hydrogen—Oxygen Mixtures in the Initial Pressure Range of 1 to 100 Abat," *Fizika Goreniya i Vzryva* **6**(3), 406–407 (September 1970) (In Russian) See **Section D.**

Markstein, G. H. and de Ris, J. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Upward Fire Spread over Textiles," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1085 (1973)

Subjects: Textiles, burning of; Burning rate of textiles; Fabric burning

Authors' Abstract

Two-dimensional upward flame spread over cotton fabrics was found experimentally to be an accelerating process that acquires a turbulent character after a brief laminar period. With the fabric inclined with respect to the vertical, the heat transfer from the bottom flame was found to control the spread rate. Mass-burning rate $\dot{m}_b''$, and mass heating rate $\dot{m}_f''$ had constant values of 19.6 and 57.9 g/m^{2}s, respectively, independent of angle of inclination, relative humidity, and fabric mass per unit area.

The transport processes that control upward flame spread were simulated in a steady-state gas-burner experiment that permitted measurement of mass- and heat-transfer rates for various burner orientations. In agreement with the fabric-burning experiments, a semi-empirical analysis, based on the gas-burner data, showed that the accelerating spread rate asymptotically attains a steady state that normally cannot be reached, however, with practical dimensions of the test fabric. The asymptotic spread rates computed from the experiments depended strongly on angle of inclination and moderately on ambient relative humidity, varying between 0.20 and 0.45 m/s.

Nolan, P. F., Brown, D. J., and Rothwell, E. (Department of Chemical Engineering and Fuel Technology, University of Sheffield, Sheffield, England) "Gamma-Radiographic Study of Wood Combustion," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1143 (1973)

Subjects: Wood combustion; Combustion of wood; Char structure; Gamma-ray study of wood combustion

Authors' Abstract

A gamma-ray attenuation technique has been developed to study the thermal decomposition of wood. The changes in density in isothermal planes have been determined from changes in the attenuation of Cesium-137 gamma rays by means of the Beer–Lambert relationship. Temperatures inside the wood have been measured by using fine thermocouples, so that both density–time and temperature–time histories have been obtained for the decomposing wood block. Assuming that a first-order reaction-rate equation can be applied, the temperature-time history is used with different assumed values of A, the pre-exponential factor, and E, the activation energy, to give theoretical density–time curves to compare with the experimental ones.

The best agreement between theory and experiment was found when $A = 1 \times 10^8$ sec^{-1} and $E = 30$ kcal mol^{-1} for a range of blackbody heat fluxes from an infrared heater incident on the wood surface of 0.5 to 4 cal sec^{-1} cm^{-2}.

Peeters, J. (Departement Scheikunde, Katholieke Universiteit, Leuven, Belgium) **and Mahnen, G.** (Laboratoire de Physico-chimie de la Combustion, Université Catholique de Louvain, Belgium) "Reaction Mechanisms and Rate Constants of Elementary Steps in Methane—Oxygen Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 133 (1973)

Subjects: Flame structure; Methane—oxygen flame structure and kinetics; Kinetics of methane—oxygen flames

Authors' Abstract

The concentrations of all stable and unstable species have been measured in the reaction zone of lean and stoichiometric methane–oxygen flames burning at 40 torr.

The rate constant of Reaction [1], $CH_4 + OH \rightarrow CH_3 + H_2O$, was found to be $k_1 = 3 \times 10^{13} \times \exp(-6000/RT)$ mol^{-1} cm^3 sec^{-1}. In stoichiometric flames, half of the fuel is consumed via Reaction [1′], $CH_4 + H \rightarrow CH_3 + H_2$, and at $T =$ 1600°K, k_1' is reported to be 3.2×10^{12}. It is shown conclusively that the great majority of the methyl radicals is removed by Reaction [2], $CH_3 + O \rightarrow CH_2O +$ H, with $k_2 = 1.3 \times 10^{14} \exp(-2000/RT)$. The rate-determining step is a reaction resulting in an increase of the number of particles, Reaction [13]: $CH_2O + M \rightarrow CO + H_2 + M$; the value $k_{13} = 2.1 \times 10^{16} \exp(-35{,}000/RT)$ was derived. Another part of the formaldehyde disappears via Reaction [3]: $CH_2O + OH \rightarrow CHO + H_2O$; the rate constant is $k_3 \simeq 2.3 \times 10^{13}$ in the range $T = 1400°\text{–}1800°K$. Most of the CHO radicals react with O_2: $CHO + O_2 \rightarrow HO_2 + CO$; $k_4 \simeq 3 \times 10^{13}$ at $T = 1600°K$. In lean flames, HO_2 is removed mainly by reactions involving OH and O: $HO_2 + OH(O) \rightarrow O_2 + H_2O(OH)$; and $k_5 \simeq 5 \times 10^{13}$ at $T = 1600°K$. Carbon dioxide is formed by Reaction [6]: $CO + OH \rightarrow CO_2 + H$; the rate constant was found to be $k_6 = 2.8 \times 10^{11}$ at $T = 1750°K$, and the activation energy $E_6 = 5.5 \pm 2$ kcal/mol in the range $T = 1500°\text{–}1900°K$.

In the burned gas of lean flames, the radical "pool" decays by Reaction [11]: $H + O_2 + M \rightarrow HO_2 + M$, the rate constant (for $M = O_2$) being $k_{11} = 2.5 \times 10^{15}$ at $T = 1900°K$.

River, B. H. (Forest Products Laboratory, U.S. Forest Service, Madison, Wisconsin) "Mastic Construction Adhesives in Fire Exposure," *Forest Service Research Paper FPL 198, U.S. Department of Agriculture* (1973)

Subjects: Adhesives, mastic; Fire exposure; Fire resistance; Tests for adhesives

Author's Abstract and Conclusions

Describes two basic methods for testing the heat resistance of mastic construction adhesives. Thirty diversified adhesives were classified as either heat-resistant or nonheat-resistant. Heat-resistant adhesives in wood-to-wood joints withstood temperatures exceeding 550°F and a load of 2 pounds per square inch. Nonheat-resistant adhesives failed at temperatures generally below 300°F.

The fire resistance of some mastic adhesives may depend on the substrate bonded. The bench test method for fire resistance offers a way to rapidly screen an adhesive's fire performance with a wide variety of substrates, including not only wood and aluminum, but also steel, gypsum board, hardboard, and other materials.

Furnace tests confirmed that, of the adhesives tested, there were two distinct groups of adhesives based on heat resistance, those which are as durable as wood and those which are not. The bench test can distinguish between these groups with good accuracy. Formulation variables so strongly affect mastic adhesive's properties that generalizations about the relative heat resistance of different elastomer bases for mastic adhesives would be misleading.

Lastly, not all the so-called heat-resistant adhesives develop heat resistance within a period of one month, otherwise considered an adequate cure time. The bench test could be used to study the rate of development of heat resistance.

Rogowski, B. and Malhotra, H. L. (Joint Fire Research Organization, Borehamwood, Herts., England) "Fire Tests on Two System-Built Houses," *Fire Research Technical Paper No. 29, Joint Fire Research Organization* (1973) See **Section M.**

Romodanova, L. D., Pepekin, V. I., Apin, A. Ya., and Pokhil, P. F. (Moscow, U.S.S.R.) "Relationship between the Burning Velocity of a Mixture and the Chemical Structure of the Fuel," *Fizika Goreniya i Vzryva* **6**(4), 419–424 (December 1970) (In Russian) See **Section D.**

Thomas, P. H. (Building Research Establishment, Fire Research Station, Borehamwood, Herts., England) "Behavior of Fires in Enclosures—Some Recent Progress," *Fourteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, p. 1007 (1973)

Subjects: Fires in enclosures; Enclosed fires; Burning rate of enclosed fires; Ventilation of enclosed fires; Building fires

Author's Abstract

Several building-research laboratories have been undertaking cooperative research on crib fires in single compartments. Four different shapes of compartment have been used on three different scales, the sizes of compartment ranging from 0.5 x 1 x 0.5 m high to 6 x 6 x 1.5 m high.

This paper discusses some features of the results, notably the finding that the rate of weight loss in fully developed fires is not simply proportional to $A_W H^{1/2}$ (where A_W is the window opening and H its height); the relationship between them involves the shape and surface area of the compartment.

There is an inverse relation between the rate of burning and temperature for small changes in crib porosity, as well as for large changes in $A_W H^{1/2}$. Fires growing from a small source are also being studied. The preliminary work is designed to survey the problem in breadth rather than any one factor in depth; the effect of size of window opening, size and position of ignition source, and the dispersion of the crib fuel, all appear to have influences of comparable order.

Some data for free-burning cribs are also presented in terms of the correlation devised by Block; some similarities and discrepancies are reported.

Waibel, R. T. (Fire Science Centre, University of New Brunswick, Fredericton, New Brunswick, Canada) **and Essenhigh, R. H.** (Combustion Laboratory, Pennsylvania State University, University Park, Pennsylvania) "Combustion of Thermoplastic Polymer Particles in Various Oxygen Atmospheres: Comparison of Theory and Experiment," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1413 (1973)

Subjects: Polymer combustion; Particles of polymers; Oxygen combustion of polymers

Authors' Abstract

The diffusional theory of oil-drop combustion has been modified to include mass vaporization by pyrolysis, in order to apply this theory to polymer-droplet combustion. The predictions of the resulting theory are compared with experimental results obtained for the combustion of polymer particles in mixtures from 10% to 70% O_2 in N_2. In agreement with experiment, the modified theory still predicts the "square law" relationship found for oil droplets,

$$t_b = Kd_o^2,$$

where t_b is the burning time for a droplet initially of diameter d_o. In addition, a comparison between the predicted droplet temperature variation with time and experimental data gives an insight into the pyrolysis process. The polymers appear to pyrolyze by a surface or pseudo-surface reaction, with temperature rising with time.

H. Chemical Aspects of Fires

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (Pittsburgh Mining and Safety Research Center, U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Flame-Structure Studies of CF_3Br-Inhibited Methane Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 367 (1973) See **Section G.**

Combourieu, J., Le Bras, G., and Paty, C. (Centre de Recherches sur la Chimie de la Combustion et des Hautes Températures et Faculté des Sciences d'Orléans, Orléans, France) "Reaction of H Atoms with CH_2Cl_2 Application to the Inhibition of Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 485 (1973)

Subjects: Kinetics of inhibition reactions; Hydrogen atom reaction; CH_2Cl_2; Flame inhibition

Authors' Abstract

The reaction kinetics of atomic hydrogen with dichloromethane have been investigated in a discharge-flow system in the 298°–460°K temperature range, and at total pressures near 1 torr. A quadrupole mass spectrometer was adapted for the simultaneous determination of atomic hydrogen and stable species concentrations.

For the $H + CH_2Cl_2$ over-all reaction, the stoichiometry

$$([H]_0 - [H])/([CH_2Cl_2]_0 - [CH_2Cl_2])$$

determined for various initial $[H]_0/[CH_2Cl_2]_0$ ratios always exceeds 4. The products have been identified as HCl, H_2, CH_4, C_2H_2, and C_2H_4.

The rate constant of the initial step,

$$H + CH_2Cl_2 \rightarrow HCl + CH_2Cl, \quad (1)$$

was found to be $k_1 = 1.8 \times 10^{-11} \exp(-6100/RT)$ cm³ molecule⁻¹ s⁻¹ from 298° to 460°K.

Evidence was found for the occurrence of secondary reactions,

$$H + HCl \rightarrow Cl + H_2, \quad (2)$$

$$Cl + CH_2Cl_2 \rightarrow HCl + CHCl_2. \quad (3)$$

The use of D atoms instead of H atoms gives further information on the reaction mechanism, which is discussed. Reaction (1) may be the inhibiting step in the mechanism of flame inhibition by CH_2Cl_2.

Eberius, K. H., Hoyermann, K., and Wagner, H. Gg. (Institut für Physikalische Chemie der Universität, Göttingen, West Germany) "Structure of Lean Acetylene—Oxygen Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 147 (1973) See **Section G.**

Ksandopulo, G. I., Kolesnikov, B. Ya., Zavadskii, V. A., Odnorog, D. S., and Elovskaya, T. P. (Alma Ata, U.S.S.R.) "Mechanism of the Inhibition of Combustion of Hydrocarbon—Air Mixtures by Finely Dispersed Particles," *Fizika Goreniya i Vzryva* **7**(1), 92–99 (March 1971) (In Russian) See **Section E.**

Lipska, A. E. (Stanford Research Institute, Menlo Park, California) "The Effect of Flame Retardants on Thermal Degradation of α-Cellulose in Nitrogen," *Annual Report SRI Project No. PYU–8150 under Defense Civil Preparedness Agency Contract No. DAHC20–70–C–0219* (no date)

Subjects: Pyrolysis; Decomposition of cellulose; Cellulose decomposition; Flame retardants in cellulose; Char; Thermal degradation of cellulose

Author's Abstract

Measurements for use in assessing the Parker-Lipska model for decomposition of cellulose are reported. These include changes in molecular weight during isothermal pyrolysis and increases in char yield and weight-loss rate due to retardant treatment. These experiments also investigated the role of 1,5-anhydro-2,3-deoxy-β-D-pent-2-eno-furanose (a major product of thermally degraded cellulose and levoglucosan) in the char-formation process of fire-retarded cellulose. The isolated furnose derivative, both in the neat form and in the presence of $NH_4H_2PO_4$, was pyrolyzed and its degradation products were analyzed by means of a gas chromatograph.

At 276°C, initial pyrolysis of α-cellulose results in an abrupt decrease in average molecular weight and is followed by a linear decrease over a prolonged period of heating. Increased yields of char and rates of degradation due to the basic and neutral retardants were found to be in quantitative agreement with the predictions of the Parker-Lipska model for decomposition of cellulose. Effects of the acidic retardants, however, were not in agreement with the prediction. These results sug-

gest that some modification of the model is in order. The results of the pyrolysis experiments on furanose derivative support the contention that the excess yield of char in retardant-treated cellulose is due to the degradation of secondary products of cellulose decomposition rather than of the cellulose molecule itself.

Peeters, J. (Departement Scheikunde, Katholieke Universiteit, Leuven, Belgium) **and Mahnen, G.** (Laboratoire de Physico-chimie de la Combustion, Université Catholique de Louvain, Belgium) "Reaction Mechanisms and Rate Constants of Elementary Steps in Methane—Oxygen Flames," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 133 (1973) See **Section G.**

Romodanova, L. D., Pepekin, V. I., Apin, A. Ya., and Pokhil, P. F. (Moscow, U.S.S.R.) "Relationship Between the Burning Velocity of a Mixture and the Chemical Structure of the Fuel," *Fizika Goreniya i Vzryva* **6**(4), 419–424 (December 1970) (In Russian) See **Section D.**

Sumi, K. and Tsuchiya, Y. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "Combustion Products of Polymeric Materials Containing Nitrogen in their Chemical Structure," *Journal of Fire & Flammability* **4,** 15 (January 1973)

Subjects: Products of combustion; Polymer combustion; Toxic gases; HCN

Authors' Abstract

Five materials that contain nitrogen were burned in a flask at 800°C, and the amounts of hydrogen cyanide, carbon monoxide, and carbon dioxide produced were quantitatively analyzed by gas chromatography. The harmful effects of these products to the resulting atmosphere were then evaluated. The results vividly illustrate the potential danger of HCN to a fire environment when materials containing nitrogen are involved in fire.

Woolley, W. D. and Wadley, A. I. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Production of Oxides of Carbon from the Thermal and Thermal-Oxidative Decomposition of Flexible Polyurethane Foams," *Fire Research Note No. 966, Joint Fire Research Organization* (April 1973)

Subjects: Gas chromatography; Mass spectrometry; Polyurethane foam; Pyrolysis; Toxic gas; Carbon monoxide; Carbon dioxide

Authors' Summary

The production of oxides of carbon from the thermal and thermal-oxidative decomposition of a polyester and polyether flexible polyurethane foam, parent polyols, and yellow smoke has been studied at temperatures between 200 and 1000°C by gas chromatography. In inert atmospheres virtually the entire oxygen content of each foam is released as total oxides of carbon at 1000°C. At this temperature, the polyester foam releases 260 and 145 mg/g of carbon monoxide and carbon dioxide, respectively, whereas the polyether foam releases 400 and 42 mg/g, respectively. Under oxidative conditions the maximum carbon monoxide yields (295 and 440 mg/g for the polyester and polyether foams, respectively) are generated at 600°C whereas the maximum carbon dioxide yields are released at 1000°C (960 and 715 mg/g for the polyester and polyether materials).

I. Physical Aspects of Fires

Beyreis, J. R., Monsen, H. W., and Abbasi, A. F. (Fire Protection Department, Underwriters' Laboratories, Inc.) "Properties of Wood Crib Flames," *Fire Technology* 7, 145 (1971)

Subjects: Wood crib fires; Crib fires; Emissivity of wood fires; Heat transfer

Authors' Summary

These experiments show that the convective heat transfer coefficient for the flames and hot gases from the burning wood is in the range of 3 to 18 Btu/hr ft^2 °F. This compares with the range of 3.5 to 15.5 Btu/hr ft^2 °F observed for fully developed room fires.

Flame emissivity was shown to be a function of flame thickness along the line of view, increasing as thickness increases. The relationship between emissivity and thickness is shown in Fig. 8 and Eq. 7.

$$\epsilon = 1 - e^{-0.158x} \qquad (7)$$

where ϵ is emissivity and x is flame thickness, ft.

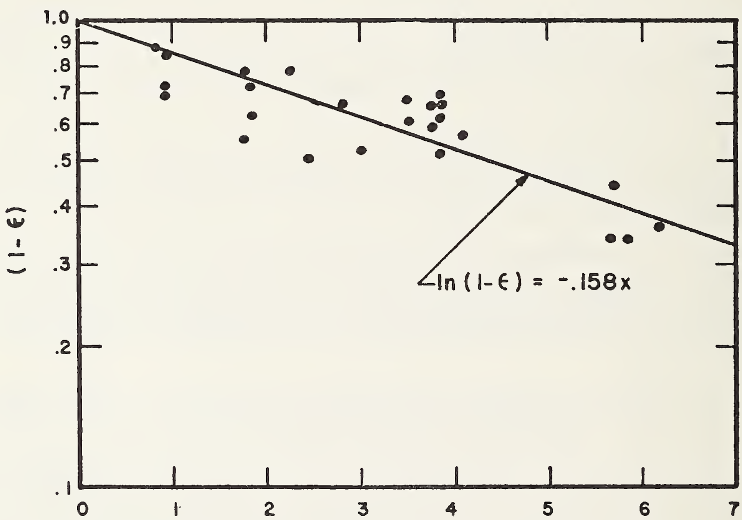

Fig. 8. Flame emissivity vs. flame thickness for wood crib flames.

The information reported here concerning the emissivity and convective heat transfer coefficient for wood flames is useful in performing calculations of the heat transfer from such flames to structural members within or near the flames.

Itoya, S. (Fire Research Institute of Japan, Tokyo, Japan) "Electric Conduction through Flame," *Report of Fire Research Institute of Japan No. 36*, p. 18 (March 1973)

Subjects: Flame electric conduction; Electric conductivity of flames; Ions

Author's Abstract

With marked growth in the utilization of electric power and the density of population in urban areas, the number of buildings positioned close to high voltage lines is increasing, while it is getting difficult to stop power supply even when a building fire takes place near such power lines. Accordingly, firemen have often to fight fire near the high voltage live lines, exposed to a possible danger of electric shock by way of fire flames.

There are many works on the ionization in flames, but hardly any of them deals with the case of real fires with which firemen have to compete. Therefore, experiment on the ionization of flames similar to actual fires have been performed, and the results are summarized as follows.

Electric characteristics of various flames of about 20 cm in diameter with dc voltage applied to the electrodes immersed in the flame are shown. It is noticeable that the flames of burning woods show the higher electric conductivity than those of other fuels.

Electric characteristics of flames were also measured for electrode gap ranging from 4 mm to 1 m with ac application, the results of which are shown. Through these results, it is clear that the potential drop in the region close to the electrode for ac is very small, and that the average volume resistivity will be approximately 100 kΩ-cm. The ac arc discharge voltage in flames will be about 1/50 of that in ordinary atmosphere.

Taking these facts into account, the firemen must be sufficiently cautious against the danger of electric shock by way of flame when engaged in fire fighting practices near the power lines.

Kawasaki, M. (Fire Research Institute of Japan, Tokyo, Japan) "Experimental Study of Static Electrification of High-Pressure Vapour Jet (I)," *Report of Fire Research Institute of Japan No. 36,* p. 24 (March 1973)

Subjects: Static electricity; Jets; Electrification

Author's Abstract

The electrification in the vapour jet of various liquids was studied.

The vapour was discharged from a nozzle of diameter 0.5 mm set at the wall of the enclosed vessel, in which the vapour pressure was elevated to about 100 kg/cm^2 by heating and vaporizing the liquid. The electric charge generated in the jet was collected by a probe of a brass electrode of 3 mm in diameter. The charge quantity per second at various points in the vapour jet of 16 kinds of liquids was measured in the pressure, range 10-80 kg/cm^2. The humidity of ambient atmosphere was kept constant during the experiment.

(1) The electric charges, collected per unit time (s) at the point of 50 cm from the nozzle in the jet axis at the discharge pressure of 50 kg/cm^2 were about 0.4×10^{-9} C for *o*-xylene; 0.4×10^{-9} C for *m*-xylene; very small for *p*-xylene; 175×10^{-9} C for *n*-butyl alcohol; 10×10^{-9} C for *i*-butyl alcohol; 8×10^{-9} C for *sec*-butyl alcohol; 320×10^{-9} C for *n*-propyl alcohol; 20×10^{-9} C for *i*-propyl alcohol; 80×10^{-9} C for acetone; 70×10^{-9} C for methyl alcohol; 60×10^{-9} C for ethyl alcohol; 100×10^{-9} C for water. They have all dipole moments. However, vapours of benzene, *n*-hexane and carbon tetrachloride which have no dipole moments, were not electrified.

(2) The charge increased with the vapour pressure in most liquid, except the acetone and *n*-butyl alcohol.

It seems that the electric charge in the jet vapour is related to the dipole moment of the liquid.

J. Meteorological Aspects of Fires

Garris, C. A. (Departamenta de Ingenieria, Instituto Venezolano de Investigaciones Cientificas, Caracas, Venezuela) **and Lee, S. L.** (Department of Mechanics, State University of New York, Stony Brook, New York) "A Theory for Multiple Fire-Whirl Formation," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1063 (1973)

Subjects: Fire whirls; Whirls in fires; Vorticity in fires; Bouyancy driven flows

Authors' Abstract

In an effort to gain a better understanding of the mechanics involved in the formation of vortices in buoyancy driven flows, an analysis on the stability of the laminar free convection, due to a line source of heat with ambient shear, was performed by numerical solution of a viscous linear stability equation.

The formation yielded a curve of neutral stability, based on plume thickness and ambient shear, delineating stable and unstable domains. It was thereby indicated that increased buoyancy increases stability at a given elevation in the flow field, and that the instability first occurs at a critical elevation. This critical elevation increases with buoyancy strength, but decreases with ambient shear.

The solution yielded that the disturbed motion must be a standing-wave phenomenon, of the type typically developing into vortex flows. For a given disturbance wavelength, the analysis demonstrated a periodic row of vortices, and an optimization analysis of all wavelengths indicated that the flow should break up into a vortex pattern at a most unstable wavelength or vortex spacing upon the attainment of a most unstable plume thickness Reynolds Number. These results have been found to agree closely, in functional form, with experimental results on the formation of multiple fire whirls.

In the natural occurrence of vortices, the analysis suggested that the vertical distribution of ambient vorticity is a determinant factor. It was also indicated that a strong enough convection column can overpower the ambient vorticity and thereby prevent or destroy a vortex flow.

K. Physiological and Psychological Problems from Fires

Melinek, S. J., Woolley, S. K. D., and Baldwin, R. (Joint Fire Research Organization, Borehamwood, Herts., England) "Analysis of a Questionnaire on Attitudes," *Fire Research Note No. 962, Joint Fire Research Organization* (March 1973)

Subjects: Safety attitudes; Survey; Cost-benefit analysis; Questionnaire analysis

Authors' Summary

This paper is an analysis of the results of a questionnaire, distributed during the Open Days at the Fire Research Station in 1972, which was designed to assess public awareness of risks and attitudes towards risks for the purpose of helping to establish a rational basis for expenditure on safety measures. The questions examine the perceived causes of accidents, the effects of magnitude and frequency of accidents on public concern, public assessment of relative risks, and willingness to take risks. The sample was biased, but some tentative conclusions are possible.

Woolley, W. D. and Wadley, A. I. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Production of Oxides of Carbon from the Thermal and Thermal-Oxidative Decomposition of Flexible Polyurethane Foams," *Fire Research Note No. 966, Joint Fire Research Organization* (April 1973) See **Section H.**

L. Operations Research, Mathematical Methods, and Statistics

Chandler, S. E. (Joint Fire Research Organization, Borehamwood, Herts., England) "Preliminary Analysis of Fire Reports from Fire Brigades in the United Kingdom, 1972," *Fire Research Note No. 967, Joint Fire Research Organization* (March 1973)

Subjects: Fire statistics; Fire casualties; Fire brigade reports; United Kingdom fire reports

Author's Summary

A preliminary analysis shows that there were 290,343 fires attended by fire brigades in the United Kingdom in 1972. Fatal casualties reached an all-time high of 952 of which 12 were fire brigade personnel (seven in one fire); the number of nonfatal casualties was 5,963. The direct financial loss due to fire in the United Kingdom was estimated by the British Insurance Association as £141.2 M.

Maskell, D. V. (Joint Fire Research Organization, Borehamwood, Herts., England) "Cost of Fire Protection: Towards a Definition," *Fire Research Note No. 898, Joint Fire Research Organization* (February 1973)

Subjects: Fire protection; Economics; Cost of fire protection

Author's Summary

This is the first part of a study of the cost of fire protection to the nation as a whole aimed at giving details of the various categories that go to make up the account, i.e., passive, active, and indirect measures. Large sections of this account are vague in content or ill defined and before any real cost assessment can be made the subject must first be defined.

This first report offers such a definition which, it is hoped, will form the basis of future cost exercises. Its purpose is essentially that of formulating a framework upon which any cost of fire protection study could be fixed such that in time these studies could be combined to produce an overall picture.

Ramachandran, G., Eveleigh, C., and Hudson, E. (Joint Fire Research Organization, Borehamwood, Herts., England) "Large Fires During 1971," *Fire Research Note No. 956, Joint Fire Research Organization* (January 1973)

Subjects: Fires, large; Fire loss; Fire statistics

Authors' Summary

This note contains an analysis of large fires which occurred during 1971. These are defined as fires which are estimated to have cost £10,000 or more in direct damage. There were 1252 such fires during 1971 resulting in a total loss of £81.9 million. Of these, 51 started in outdoor hazards, some of which spread to buildings.

Simard, A. J., Graham, J. D., and Muir, A. S. (Forest Fire Research Institute, Department of the Environment, Ottawa, Ontario) "Development of Computer Processing Techniques for Individual Forest Fire Report Data," *Information Report FF–X–40, Forest Fire Research Institute, Canadian Forestry Service* (July 1973)

Subjects: Forest fires; Computer processing

Authors' Abstract

The relationships between varying types of problems, analytical techniques, and data availability are discussed. The nature, characteristics, and availability of forest fire data is also discussed. A data processing procedure is presented, whereby raw uncoded, incomplete, and sometimes inaccurate forest fire data is converted to a uniform, complete, and reasonably accurate data file. The last part of the report is devoted to procedures for filling in missing information. Lastly, the appendices contain all of the codes used in this project.

M. Model Studies and Scaling Laws

de Ris, J., Kanury, A. M., and Yuen, M. C. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Pressure Modeling of Fires," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1033 (1973)

Subjects: Pressure modeling; Modeling of fires (by pressure); Scaling of fires

Authors' Abstract

It is demonstrated both theoretically and experimentally that laboratory-scale fires at high pressure can accurately model large-scale fires at atmospheric pressure, provided the product of pressure-squared times length-cubed (p^2l^3) remains invariant. These modeling laws satisfy the complete set of (laminar-turbulent) Navier-Stokes combustion equations. The present study models not only steady burning but also the solid-phase heat and mass transfer, fire spread, and other transient phenomena, provided two time scales, one for the gas-phase and another for the solid-phase, are defined. The accuracy of this modeling scheme rests upon the assumptions: (1) chemical reaction kinetics are unimportant in fires; and (2) fire radiation, if important, is proportional to the rate of combustion. The accuracy of our experimental burning rate correlations and our preliminary radiation measurements suggest that both these assumptions are valid for typical fire situations.

The measured steady turbulent burning rate per unit width of the wall, for both inside and outside burning of Plexiglas, correlated successfully against the Grashof Number to the 0.31 power. Similar correlations for pine wood cylinders yielded a

0.28 power. Furthermore, extensive flame-spread measurements of McAlevy and Magee confirm the transient hypothesis of the pressure-modeling concept.

In assessing the pressure-modeling concept as a practical tool of fire research, we have now considerable evidence to support its accuracy for free burning and spreading fires. However, we have not, as yet, examined its accuracy in modeling more complex fire phenomena, such as flashover, ignition, extinction, reradiation, burning of objects within their recirculated products, and suppression of fires with water sprays. Each of these phenomena requires further theoretical and experimental study before the full generality and power of the pressure-modeling concept as a practical tool of fire research can be assessed.

Forest Products Laboratory, Madison, Wisconsin. "FPL Facility for Evaluating Strength-Performance of Walls Exposed to Fire," *U.S.D.A. Forest Service Research Paper FPL 199* (1973)

Subjects: Fire performance of walls; Wall fire performance

Author's Abstract

To simulate the design loads on wall panels of homes when one surface is exposed to fire, the FPL facility used for 40 years to evaluate 10- by 10-foot panels was modified so that: (1) It would support a conventional 8-foot-high by 10-foot-wide wall panel of a home; (2) it would apply compressive, edgewise, vertical loads along the 10-foot edge; (3) the applied loads would be uniformly distributed by a hydraulic system of jacks; (4) the loads could be monitored by electronic load cells; and (5) the system would have a load capacity of 40,000 pounds.

It was estimated that design loads on such a panel in a first-story wall of a two-story home would be 1,250 pounds per linear foot. The capacity of this facility exceeds the minimum requirements because it is intended to accommodate future considerations.

Forest Products Laboratory, Madison, Wisconsin. "Correlation of ASTM Exposure Tests for Evaluating Durability of Fire-Retardant Treatment of Wood," *U.S.D.A. Forest Service Research Paper FPL 194* (1973)

Subjects: Exposure tests; Fire retardants; Retardants

Author's Summary

A cooperative study was carried out to determine the equivalency of two alternate methods of exposure testing described in ASTM Standard D 2898-70T, "Tentative Methods of Test for Durability of Fire-Retardant Treatment of Wood." Matched specimens of ⅝-inch Douglas-fir plywood, pressure treated with leach-resistant and nonleach-resistant fire-retardant chemical systems, were exposed by methods A and B of the standard and fire tested in the 25-foot and 8-foot tunnel furnaces. Method A is the 12-week "rain test" exposure in use at Underwriters' Laboratories, Inc., and method B is the 1,000-hour accelerated weathering chamber apparatus in use at the Forest Products Laboratory.

The two methods differ in the cycling time of waterspray and drying. However, the percent water pick up by treated specimens during the water-spray periods of the exposure cycle was approximately the same for both methods, 20 to 24 percent of initial weight. During the drying periods, specimens under method A were brought back to initial weight or below, while specimens under method B retained about an additional 6 to 8 percent water.

The flame-spread results on the treated specimens by both fire test furnaces did not show any significant difference in the leaching effect between the two exposure methods. Thus overall exposure by either method can provide conditions that differentiate between leach-resistant and nonleach-resistant treatments.

Harmathy, T. Z. (Division of Building Research, National Research Council of Canada, Ottawa, Canada) "A New Look at Compartment Fires, Parts I, II," *Fire Technology* **8,** 196–217, 326–351 (1972) See **Section G.**

Heskestad, G. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Modeling of Enclosure Fires," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1021, (1973)

Subjects: Modeling of fires; Fire modeling; Enclosed fire modeling; Crib fires

Author's Abstract

An approximate modeling technique for enclosure fires is proposed and partially tested. The technique is based on the hypothesis that the combustion of a fuel pile in an enclosure, relative to the combustion of the same pile in open space (unconfined), depends on associated differences in the fluid-mechanical properties and the chemical composition of the gas supply to the fire.

Previous work on unconfined fires of wood cribs is reviewed and consolidated in a form which relates the burning rate per unit exposed surface area to stick thickness and a function of a porosity factor. This factor differs in a small but significant way from a porosity factor proposed previously by Gross. Application of the modeling hypothesis, under the assumption of large Grashof Numbers for the convective flow, then leads to the following sufficiency conditions for predicting fire properties on one enclosure scale from experiments on another scale: (1) the enclosures must be geometrically similar; (2) unconfined burning rates of the fuel piles in the two enclosures must be in the ratio of the linear-scale ratio to the 5/2-power; (3) porosities of the fuel piles must be conserved from one scale to the other; and (4) the thermal properties of the walls must be modeled for proper response.

Experiments available for testing the modeling technique did not satisfy the third and fourth conditions. Nevertheless, data on burning rates, selected gas species (oxygen, carbon monoxide, carbon dioxide), and over-all fire behavior conformed well with the modeling hypothesis. Temperatures did not conform, evidently because wall properties had not been modeled. No discernable effects of fuel porosity were observed, but the scope of the experiments was too limited to allow a firm conclusion on porosity effects.

Rogowski, B. and Malhotra, H. L. (Joint Fire Research Organization, Borehamwood, Herts., England) "Fire Tests on Two System-Built Houses," *Fire Research Technical Paper No. 29, Joint Fire Research Organization* (1973)

Subjects: Tests; House burns; System-built houses

Authors' Summary

Full-scale fire tests have been carried out on two system-built houses with structural steel frames, designed to comply with the basic principles of fire protection; individual elements were incorporated whose fire resistance had been confirmed by furnace test techniques.

The performance of the structure as a whole when subjected to fire conditions of a severity typical of a dwelling fire was investigated and where possible compared with the results of furnace tests. The *ad hoc* test also allowed investigation of factors such as the performance of joints and the interaction of structures which could only be studied on laboratory scale if composite furnace facilities were available. Employing a protected steel stanchion as a calorimeter, a method of assessing the equivalent fire resistance in terms of duration on the furnace test was used to confirm that the individual elements and the junctions between them provided the required standard of fire performance.

The results of the first test showed that, although the overall performance of the houses under normal loading conditions was satisfactory, minor modifications were necessary to ensure that the appropriate degree of fire resistance could be achieved under conditions of full design load.

Thomas, P. H. (Building Research Establishment, Fire Research Station, Borehamwood, Herts., England) "Behavior of Fires in Enclosures—Some Recent Progress," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, p. 1007 (1973) See **Section G.**

N. Instrumentation and Fire Equipment

Benson, S. P., Griffiths, D. J. and Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "A Five-Litre Per Minute Standard Foam Branchpipe," *Fire Research Note No. 971, Joint Fire Research Organization* (1973)

Subjects: Branchpipe; Foam

Authors' Summary

Constructional details of a five litre per minute foam branchpipe are given. A recommended procedure is described for its use in a standard laboratory test method for the determination of foam properties. The investigations leading to the design of this branchpipe, and to the method of determining the 25 per cent drainage time of the foam, have been decribed in Fire Research Notes Nos. 970 and 972. This report is confined to the constructional details and to a suggested standard operating procedure, in order to make it convenient for those who wish to use it for this purpose.

Benson, S. P., Griffiths, D. J., Tucker, D. M., and Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "Foam Branchpipe Design," *Fire Research Note No. 970, Joint Fire Research Organization* (May 1973)

Subjects: Branchpipe; Foam

Authors' Summary

An experimental model branchpipe, with a capacity of 5 l/min (1.1 g/min) of liquid, was used to investigate how the branchpipe configuration affects performance. The expansions, 25 per cent drainage times, shear stresses, and jet throws, of the foams were measured. A representative range of foam liquids was used and concentration and supply pressure varied. Some principles of design were determined. The model was compared with larger branchpipes.

A specific design for a 5 l/min branchpipe, which is simple to construct, and has good characteristics, is described. (This branchpipe could be used as a laboratory reference standard and for the convenience of those who may wish to use it for this purpose, engineering drawings and a recommended test procedure, are being issued as a separate Fire Research Note No. 971.)

McQuaid, J. and Wright, W. (Safety in Mines Research Establishment, Department of Trade and Industry, Sheffield, England) "The Response of a Hot-Wire Anemometer in Flows of Gas Mixtures," *International Journal of Heat Mass Transfer* **16,** 819–828 (1973)

Subjects: Anemometer response; Hot-wire anemometer

Authors' Abstract

An investigation of the problem of measuring turbulence quantities in flows of gas mixtures by means of hot-wire anemometry is described. In view of the lack of a reliable heat-transfer law for fine wires in flows with variable gas properties, an entirely empirical approach is adopted. Attention is paid initially to the air/carbon dioxide system, and it is shown that a simple calibration procedure is possible. An assessment is made to determine a suitable gas as a marker for flows in which turbulence measurements are to be made, and it is concluded that argon is to be preferred to carbon dioxide. The procedure for measuring turbulence quantities in air/argon mixtures is discussed; the optimum arrangement is a large-diameter wire operated at low overheat ratio combined with a small-diameter wire operated at high overheat ratio.

Thorne, P. F. and Jordan, J. (Joint Fire Research Organization, Borehamwood, Herts., England) "Preliminary Experiments on the Use of Water Additives for Friction Reduction in Fire Hose," *Fire Research Note No. 959, Joint Fire Research Organization* (February 1973)

Subjects: Hose; Friction factor; Drag reduction

Authors' Summary

Measurements have been made of the Fanning friction factor (f) for 19 mm hose-reel hose and 70 mm nonpercolating fire hose for plain water and dilute (10 to 50 ppm) solutions of Polyethylene Oxide Polymer (PEO). Friction factors were reduced by about 50 per cent by the addition of PEO to the water. Passage of the dilute solutions through a small transportable fire pump destroyed the friction-reducing phenomenon. The presence of PEO in the water enhanced the coherence of water jets, contributing to increased 'throw.' The scope for the application of PEO in practical fire fighting operations is discussed.

O. Miscellaneous

Fletcher, B., McQuaid, J., and Mercer, A. (Safety in Mines Research Establishment, Department of Trade and Industry, Sheffield, England) "Some Ventilation Problems in the Underground Environment," *Tunnels & Tunnelling* (March-April 1973)

Subjects: Ventilation; Underground ventilation; Mine ventilation hazards

Authors' Abstract

Some results of research on the behaviour of a lighter- or heavier-than-air con-

taminant gas released into a ventilated tunnel are described. The research was undertaken in connection with the methane hazard in coal mines, but its applicability to various situations which might arise in vehicular tunnels in general is discussed. The propensity of the contaminant gas to form a stably stratified layer along the roof or floor of the roadway is outlined, and the recommended procedure for ensuring rapid dispersal of these types of layers is given. The effect of multiple sources is discussed, and an analysis to determine the build-up of concentration around a vehicle moving at the same velocity as the ventilation is outlined. A discussion is also included of the natural ventilation of enclosed spaces (e.g., an underground garage) by buoyancy-driven exchange flows through the access tunnels or ventilation shafts.

Fowler, L. C. (Joint Fire Research Organization, Borehamwood, Herts., England) "Collected Summaries of Fire Research Notes 1972," *Fire Research Note No. 960, Joint Fire Research Organization* (February 1973)

Subjects: Fire research; Review of fire research; Fire Research Notes; Borehamwood; Joint Fire Research Station

Author's Note

Summaries prepared for the Fire Offices' Committee

Langdon-Thomas, G. J. (Fire Research Station, Joint Fire Research Organization, Borehamwood, Herts., England) "The Fire Regulations and Their Technical Background," *The Building Regulations: Health, Administration, Fire and Safety,* Royal Society of Health, London (1973)

Subjects: Fire regulations; Technical background of fire regulations

Publisher's Note

This booklet is an excerpt from papers read before the R.S.H. Conference on "The Administrative and Safety Provisions of the Building Regulations" subsequently published as *The Building Regulations: Health, Administration, Fire and Safety* (Price 22s. 6d. from the Royal Society of Health, 90 Buckingham Palace Road, London, S.W.1).

Meetings

Third International Symposium on Combustion Processes, Kazimierz, Poland (September 24–27, 1973)

This international meeting was attended by a diverse group gathered from both Eastern and Western combustion laboratories. The interchange of technical information was lively. Direct fire research is not yet a major area of investigation in Europe. There was active interest in U.S. programs, which may lead to participation in similar programs by more combustion research groups.

R. M. Fristrom

SYMPOSIUM PAPERS*

Chemistry of Combustion

E. M. Bulewicz
"Free Radicals and Catalysis in Flames"

A. V. Merzhanov
"Theory of Gasless Combustion"

Z. G. Szabo
"A Scheme of Elementary Reactions in Hydrocarbon Oxidations"

R. R. Diaz, D. J. Waddington
"Epoxidation of Alkenes: Determination of Rate Constants for the Reaction between Alkenes and Peracelty Radicals in the Gas Phase"

A. DiLorenzo, A. D'Alessio, C. Venitozzi, S. Masi
"Spectral Studies of Soot Forming Premixed Flames"

H. Knabben, W. Kollmann, C. G. Stojanoff
"Statistical Investigation of a Turbulent Flame"

A. K. Filonenko
"Spin Combustion—New Form of Propagation of a Chemical Reaction Center"

G. B. Manelis, V. A. Strunin and Yu. J. Rubtsov
"Mechanism of the Thermal Decomposition and Combustion of Salts of Ammonia and Hydrozone"

H. Schacke, K. Schmatjke, J. Wolfrum
"Reactions of CN Radicals in the Hydrocarbon–Nitrogen System"

I. Nemes, E. Donoczy, L. Somegi, I. P. Hajdu, T. Vidoczy, D. Gol
"Modeling of Liquid-Phase Hydrocarbon Oxidation"

I. P. Borovinskaya
"Combustion Processes and Chemical Synthesis"

L. Starski, A. Pilc, I. Zaborowska
"Reduction of Explosion Properties of Carbon Disulphide by the Addition of a Second Combustible"

Gas Dynamics of Combustion

J. Chomiak
"Recent Advances in the Theory of Turbulent Flame Propagation in Premixed Gases"

V. Ya. Basevich, S. M. Kogarko
"Characteristics of a Turbulent-Flame Combustion Surface"

P. J. Van Tiggelen
"Use of Electric Field to Measure Burning Velocities"

* Papers are scheduled for publication in *Polish Annals of Combustion*.

G. G. Chernyi, S. M. Gilinskiy, S. Yu. Chernyavskiy
"Periodic Fluctuations in the Flow of a Combustible Gas Mixture near Obstacles"

H. P. Phillips
"The Use of Scale Models to Study Methane Roof Layer Explosions"

P. Wolanski, S. Wojcicki
"The Investigation of the Effect of the Laser Radiation on the Combustion Process"

H. Wilhelm
"Experiments on the Ignition Conditions and the Combustion Process in Supersonic Diffusion Flames"

S. K. Aslanov
"Study of the Stability of Frontal Turbulent Burning in a Chamber"

R. Petela, K. Wilk
"Similarity Problems of Turbulent Diffusion Flames"

S. Crescitelli, F. Napolitano, G. Russo, L. Tranchino
"Flammability Limits in Flowing Gases"

V. Volshchak
"The Effect of H and R on Combustion Parameters"

T. A. Brzustowski
"Turbulent Flame Models: II—Exact Solutions for a Vertical Flame"

A. S. Isserlin
"Modeling of Gas Combustion Processes and the Stability of Turbulent Flames"

B. Leckner
"Some Elements of Radiative Heat Transfer Calculations in Flames and Combustion Gases"

D. M. Zallen
"Chemi-ionization in Shock-Induced Methane Combustion"

N. Helwig
"Grenzspaltweiten Messwerte für Dreistoffgemische"

S. Kandefer, Z. Pietrzyk
"Flame Effects on the Solid Surface"

A. Konkel
"Self-Stabilization of a Gaseous Diffusion Torch"

Heterogeneous Combustion

W. Cybulski
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J. A. Nicholls, H. Miyajima
"Interaction of a Shock Wave with a Burning Drop"

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S. Traustel, R. Jesshor
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"The Flame Propagation in the Dust-Gas Oxidizer Mixture"

V. A. Fedosuv
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Ch. W. Kauffman, A. Wierzba
"Fuel Droplet Combustion"

D. J. Polishchuk, A. I. Grigor'ev
"Critical Conditions of Ignition of Metal Particles Taking into Account the Formation of Volatile Compounds"

M. Zembzhuski, Kh. Karch
"Kinetic Properties of Petrographic Types of Anthracite"

R. M. Fristrom
"Some Activities of the Committee on Fire Research of the National Academy of Sciences/National Research Council of the United States of America"

A. M. Levin
"Combustion Processes in Flameless Burners"

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"Ignition Characteristics of Jet Engine Combustors"

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J. Zelkowski
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I. Zuber
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L. A. Gussak, V. P. Karpov, L. I. Orel
"Formation of Nitrogen Oxide in Piston Engines with Spark and Mixing-Chamber-Flame-Jet Ignition"

G. Sitkii
"Flame Jetting in Diesel Motors"

S. Hadvig
"How to Prevent Pulsating Combustion in Boiler Plants"

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"Calculation of Combustion Process in Direct Injection Diesel Engine"

V. Konecny
"Use of a Three-Dimensional Mathematical Model in the Calculation of Steam-Boiler Combustion Areas"

T. Senkara, R. Wozniacki
"A Further Test of the Classification of the Uses of the Gas Burner"

J. Andrzejewski, P. Broszkowski, C. Bochenski, R. Saragih
"Some Consideration Concerning Ignition Quality of Diesel Fuels"

B. Erdtel
"A Simplified Method of Continuous Evaluation of Fuel-Heated Industrial Ovens and Steam Generators from a Heat-Technology Standpoint"

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THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 900 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

THE NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

THE NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U.S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and governmental organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

THE COMMISSION ON SOCIOTECHNICAL SYSTEMS is one of the major components of the National Research Council and has general responsibility for and cognizance over those program areas concerned with physical, technological, and industrial systems that are or may be deployed in the public or private sector to serve societal needs.

THE COMMITTEE ON FIRE RESEARCH functions within the Commission on Sociotechnical Systems to stimulate and advise on research directed toward the development of new knowledge and new techniques that may aid in preventing or controlling wartime and peacetime fires. The Committee was established in December of 1955 at the request of the Federal Civil Defense Administration. It is supported by the Defense Civil Preparedness Agency of the Department of the Army, the U.S. Department of Agriculture through the Forest Service, the National Science Foundation, and the National Bureau of Standards.